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ANALYTICAL PSYCHOLOGY

A PRACTICAL MANUAL FOR COLLEGES
AND NORMAL SCHOOLS

PRESENTING THE FACTS AND PRINCIPLES OF

MENTAL ANALYSIS

IN THE FORM OF SIMPLE ILLUSTRATIONS AND EXPERIMENTS, WITH 42 FIGURES IN THE TEXT AND 39 EXPERIMENTAL CHARTS

BY

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PREFACE

THIS Manual comprises a series of experiments that can be performed by untrained students of psychology without supplementary explanation on the part of the teacher and without costly and complicated apparatus.

The selection of the experiments was made chiefly with reference to their relative simplicity and ease of execution by classes of beginners in the study of psychology, but in part also with reference to their importance as illustrations of the phenomena and processes of mental life.

The experiments thus selected have been arranged in the order best suited logically to present a consistent outline of psychology and best adapted pedagogically to develop such an outline in the minds of students first approaching the study of mental phenomena from the viewpoint of the psychologist. Where compromise seemed necessary, pedagogical motives have generally outweighed purely scientific considerations. For example, the sensation which for psychology is a simple element is by no means the simplest and most familiar mental experience. To present the sensation as an object of study before other more important and better known processes have been examined by the student would seem as unsound pedagogically as it would be to begin the study of human physiology with a microscopic examination of the cells of the body.

The scope of the Manual has been purposely restricted to the analysis of the component processes of mental phenomena. The course of the analysis successively presents the essential features of apperception, perception, attention, the range and limits of consciousness, the association of mental contents and

of physiological and physical processes, the relation of mental contents to these processes, and the sensation as the mental element. Problems peculiarly connected with the processes of mental synthesis and with physiological psychology have consequently been denied special consideration, although they are frequently mentioned where necessary for the explanation of the subject-matter germane to the scope of the book.

The experiments are not intended primarily to constitute a manual of experimental psychology. Their purpose is to illustrate the facts and principles of psychology by leading the student, whether a beginner or an advanced student, to discover for himself the psychological facts upon which are based the principles of the science. The formation of correct habits of inductive reasoning, through training in psychological methods of thought, is of no small importance to any student; it is indispensable to students of pedagogy in normal schools, who require not only a knowledge of the fundamental principles of psychology, but also some training in independence of thought and action, before entering upon the more extended field of psychological experimentation in the schoolroom. This Manual can render no more gratifying service than that of diverting those who are destined to become teachers from an unwholesome subservience to psychological and pedagogical authorities toward a confident self-dependence upon their own powers of observation and reflection. The exercise of sound judgment in dealing with psychological facts is essential to any measure of success in teaching, whether such success proceed from a "natural tact" or "gift," or from the intelligent employment of the acquired facts and methods of pedagogy and psychology.

On superficial examination, the Manual may appear to lack those helps to memory and condensation — catchy definitions. A definition is often necessarily couched in such brief terms as to fail adequately to represent the ideas which it is intended to summarize. Too frequently, also, the definition is treated by

the student as an explanation conveying information not known before. For example, if a student learns that "to attend is to concentrate the mind upon an object," he has no additional information regarding the thing defined, viz., attention. If he rests satisfied with such definitions as this, he is storing his mind with material that will remain forever unassimilated. Memorized definitions of this sort can aid the student no further than to enable him to make a specious show of information before examining boards whose questions fail to test his real and vital knowledge.

But the definition is too important an aid to the memory in holding together facts already known to have been overlooked in the preparation of this Manual. The experiments have been arranged to give a consistent and progressive development of the subject-matter of the several chapters. The titles of these experiments, which are carefully worded to indicate their purport, serve the purpose of an outline of the chapters. After most of the experiments, viz., wherever the importance of the experiment seemed to warrant it, a discussion of the subject-matter of the experiment follows, in which are given many descriptive definitions. In the preparation of this descriptive and explanatory text, I have spared no labor to attain simplicity and clearness of expression. Portions of the Manual may, nevertheless, be difficult of comprehension to some. While a greater ability in the expression of scientific facts might have given the task which I undertook a more successful issue, it ought not to be expected that psychology as a branch of study in college and normal schools should be easier of comprehension than, say, mathematics.

If any measure of success attend this effort, my first acknowledgments will be due my preceptors, Professor Fullerton, from whom I learned the method and value of introspective analysis, Professor Cattell, to whom I owe my first acquaintance with the ideals of the experimental method, and

Professor Wundt, upon whose contributions to psychology, so nearly coincident with the science in its modern aspect, this volume of necessity largely draws. I was assisted in determining the form of many of the experiments by Sanford's original "Course in Experimental Psychology" and Le Conte's admirable volume on "Sight," and in a more general way by the contributions of James, Cattell, Titchener, Münsterberg, Jastrow, and Scripture. The charts and diagrams, excepting the half-tone reproductions, were prepared from original drawings. I indicate in the table of contents the sources from which I obtained a number of these illustrations. Of such obligations as will there appear in detail, I make in this place a general acknowledgment.

The present form of this Manual is the result of slow growth from a short series of illustrative experiments presented in connection with a course of lectures given in Philadelphia in 1893. Classes of graduate and undergraduate students at the University of Pennsylvania and Bryn Mawr College and classes of teachers have followed under my direction the several outlines of experiments which have served to fix the present form of the Manual. These earlier outlines have also been employed by Dr. McKeag, professor of psychology at Wilson College, and by Miss Prichard, instructor of psychology at the Philadelphia Normal School. To Dr. McKeag and Miss Prichard I am indebted for many helpful suggestions. It is also a pleasing duty to acknowledge my obligations to Mr. Twitmyer, instructor of psychology at the University of Pennsylvania, whose assistance in the conduct of laboratory courses and the preparation of the Manual for the press resulted in many improvements in its form and content.

LIGHTNER WITMER.

UNIVERSITY OF PENNSYLVANIA,
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INTRODUCTION

SECTION A

The Student's Record of the Experiments

A *psychological experiment* may be conducted with one of three somewhat different purposes in view. The expression of the result of an experiment will vary with its purpose. The purpose of an experiment may be (1) to call into existence in some individual mind those sensations, perceptions, and ideas that are to be *observed*, *analyzed*, and *described*. The observation, analysis, and description of mental states thus brought into existence may be called *experimental introspection*. The experiment may require also (2) the observation and description of some relation subsisting between the mental states and the objects (in technical language the *stimuli*) of the physical world external to the body or between such mental states and the physiological processes of the body. The result calls for *introspective analysis* on the part of the person upon whom the experiment is performed, called the *subject*, and the careful observation of the physical or physiological conditions either by the subject himself or by a second person, called the *experimenter*. The experiment may further require (3) a quantitative expression of this *psycho-physical* or *psycho-physiological* relation between a mental state on the one hand, and the physical stimuli or physiological processes on the other. This almost always requires an experiment to be performed by one

individual, the experimenter, upon another person or other persons, the subject or subjects, and may or may not require introspective analysis on the part of the subject. An experiment may often be of mixed type. The directions may call for (1) introspective analysis on the part of the subject, (2) the observation of a general psycho-physical relation, and (3) the quantitative expression of that relation in the form of an average result.

An important result that should be sought in using this Manual is the formation of habits of sound reasoning. The instructor must therefore guard against a constant tendency of the student to make generalizations and draw conclusions that are not justified by the immediate results of his experiments. A more fatal error into which the student will often fall is to use the experiment simply to illustrate some preconceived theory or some conclusion not actually obtained from the experiment itself. I find it necessary in the beginning to criticise the individual student's report of his results with great minuteness. Throughout the course, the instructor should insist upon the expression of all results in good logical form. I find it advisable to have the student make his reports in the first person rather than in the indefinite "third personal" form, which his modesty or carelessness will favor.

It is desirable that each student should keep a notebook, which ought to follow a prescribed form. A convenient notebook is made from separate sheets of note-paper size with holes punched at the top or side of the sheet. These sheets can be fastened together in any desired order, removed from time to time by the instructor for examination and correction, and afterward returned for insertion in the proper place in the notebook. The sheets and separate cardboard backs can be purchased at small expense from the stationer. The length of the reports may vary as the experiment, in the opinion of the instructor, justifies elaborate or brief treatment.

The notebook may be constructed on the following plan:

1. Enter the *heading* of the *chapter* of the Manual as given.
2. Enter under each experiment:

(*a*) The *number* and *title* of the experiment as given in the Manual. These titles and sub-titles will serve the student as a condensed outline of the contents of the experiment and also as aids to the memory in recalling the general discussion of the subject-matter of the experiment and its place in the logical development of the course.

(*b*) An exact *description* of the apparatus used and the procedure followed by the student. The Manual gives the directions which the student is to follow but not enter in his notebook. He is to report in his own language exactly what he proceeded to do in order to follow out the directions given. If the experiment is not performed in accordance with the requirements of the Manual, which may frequently happen through modifications introduced by the instructor to suit his special conditions, the student should report the procedure he has actually followed and not that of the Manual. Much time may appear wasted in compelling the student to describe the pieces of apparatus used, — time hardly to be considered as given to the study of psychology. Many students, however, greatly need the training in observation and exact description which will follow the requirement to describe exactly a few of the instruments employed by them in this course. Simple as these instruments are, the student will find it no easy task to describe in exact terms what is before him. I have found even graduate students sitting helpless before the very simple color top shown in the diagram on page 175, unable to find adequate language to describe its construction and use.

(*c*) The *result* of the experiment as made by the student. Do not let him report more than he has actually obtained as the result of his experiment.

(*d*) *Conclusions* from the result of that particular experiment. In some cases, I find it very difficult to distinguish in my own mind between a result and a conclusion. The distinction, however, is in most experiments readily observed. If, for example, a student place on the color top a small amount of white and a large amount of red, from which when the top is spun he gets a sensation of color which is indistinguishable from that which he receives from the red alone; and if he then make four successive trials, increasing on each trial the amount of white and diminishing the amount of red, until upon the fifth trial he receives a sensation which is indistinguishable from that given by white alone, the result of his experiment has given him five different sensations: a sensation of red, another of white, and three intermediate sensations of whitish-red color. His result is not a continuous series of sensations but five different sensations. This *result* justifies the *conclusion* that, if instead of five trials he had made a sufficiently great number, he could have passed by insensible gradations from red through tints of red to white. (See also the discussion on page 106 *seq.*)

3. After an experiment or a series of closely related experiments, let the student enter some general *discussion* of the facts and principles involved. This may include a summary of the discussion contained in the Manual or contributed by the instructor, and opinions reached by the student himself through original reflection.

I have often been surprised and highly gratified by the quality of these discussions and by the originality of thought and treatment displayed in the notebooks of students whose previous preparation had not led me to expect it. I cannot

help ascribing this in part to the independent method of work which this Manual requires of the student. I always place a greater value upon a little original thinking on the part of the student than upon much copying and learning of the contents of the Manual or of other text-books. The necessity for independent thinking is brought home to the student in a forcible way if a number of text-books are used for supplementary reference, each student being held responsible for one text-book and reporting from time to time before the entire class the opinions of the authority whom he has consulted on the subject-matter then under discussion. This method will show the student what a grievous error it is to suppose that psychology is a body of absolutely fixed principles, for he will find psychologists differing in their opinions as much as he and his fellow-students do. It has been my experience to find exceptional students treating the discussion of the subject-matter of certain of these experiments more satisfactorily than some well-considered text-books. The requirement of original thinking must greatly enhance the independent mental attitude of the student toward life in general; if he is to become a teacher, it must increase his insight and judgment with respect to the mental processes of the children under his pedagogical care.

The details of this plan for the notebook should be strictly adhered to, particularly in the early part of the course, when much time may be profitably spent in drilling the students properly to report their work. When somewhat advanced in the course, they may be allowed to make their reports in an abridged form, and the instructor may remit somewhat the severity with which he criticises the descriptions and discussions. The instructor will determine for himself the measure of time and effort that is due the training of the student to habits of psychological thinking and to what extent this must be abridged in order to present a sufficiently complete outline of the fundamental principles of psychology.

SECTION B

Apparatus and Books of Reference

No apparatus is necessary for the effective use of this Manual. The charts accompanying the Manual have been prepared for the special purpose of supplying material to serve as appliances for the conduct of the experiments. The student may insert these charts in his notebook in the proper place as part of his description of the experiment. If this is done with some completeness, the notebook at the end of the course will constitute an extensive outline of psychology. In schools where it is necessary to pass the book from class to class, the student can make drawings of the more important figures and insert these in his notebook. It is not advisable to spend too much time in making these drawings models of neatness and accuracy.

Many experiments call for the use of simple materials which it is supposed will be readily accessible and for which no outlay of money will be required. Among these may be mentioned a mirror, a long thin book, three coins, a cane or any long stick, receptacles for holding water, string, a feather, a weight or any small heavy object, a watch (which will probably be supplied by the student), some sugar and salt, and bottles or boxes of different sizes. In addition to this list of simple materials, a small outlay of not more than five dollars will increase the effectiveness and number of the experiments that can be employed. A few experiments call for instruments which may or may not be purchased as the instructor finds the means at his disposal, these experiments not being essential to complete the course. An appendix (page 229) gives every appliance or instrument called for in each experiment of the Manual, excepting the experimental charts which are given in a list of charts (page xi) following the table of contents.

A small collection of books of reference is desirable for effective work with some classes of students. This library should include a number of standard works of reference, text-books, the journals of psychology, and thoroughly good text-books on physics and physiology. The time given to the subject of psychology and the intellectual maturity of the student must determine the extent to which recourse will be had to these books. It is very helpful to require individual students to present short abstracts giving the views of different authors on special points, although care must be taken lest they be thrown into intellectual confusion by a multiplicity of contending opinions. If the class as a whole cannot be safely required to consult different authorities, occasional reference to standard text-books or to some special article in the current number of a periodical will be very stimulating and helpful to those more seriously interested.

SECTION C

The Selection of Experiments

The number of experiments is sufficiently large to enable the instructor to select those which are best adapted to his resources and the time at his disposal. He may employ these experiments either to present a very brief outline or to serve as the basis for a more thoroughgoing exposition of the fundamental facts and principles of psychology. A satisfactory outline of the course does not require every experiment to be performed in the detail called for by the Manual. Certain experiments may even be passed over with a few words, provided the principle involved be not omitted. Two or three different experiments are occasionally given to illustrate the same principle. The instructor may also find some experiments better suited than others for the definite purpose he may have in mind in

offering instruction in psychology. Some experiments are better adapted for larger classes, and others are more easily performed with small classes. When an experiment can be performed by the instructor, acting as an experimenter, upon all the members of the class acting as subjects, this procedure should be adopted for the purpose of saving time. Certain experiments require that the members of the class be divided into groups of two or three. In such cases I often give two or three experiments to a group of students, requiring each student to make but a single experiment upon the other members of the group, although he acts as subject for each of the other members of the group in turn. Thus the student reports the results of but one experiment, although he has the advantage of having taken part in a larger number. Where home work can be required of the student, it is possible to have certain experiments performed by the student at home. Where it is impossible to require work at home, it may still be desirable to omit the class demonstration of certain experiments that can be performed at home, suggesting to the students that the limitation of time for class work has necessitated their omission, and that it will be left to their interest in the subject voluntarily to perform these experiments without the compulsion and credit of class work.

ANALYTICAL PSYCHOLOGY

CHAPTER I

APPERCEPTION

Experiment I. **The perception of an external object is determined by apperception as well as by sensation.**

Turn over the page and look at the figure on Chart 1. What do you see at the first glance? Is it a staircase? Does your first perception remain? Can you see a staircase as though viewed from underneath? Can you see the figure as an arrangement of black lines drawn without perspective on the plane surface of the chart?

This figure is often called the staircase illusion. It is really not an illusion, unless all perception is an illusion. The external object, or *stimulus*, which acts upon the sense organ of vision is a certain number of black lines upon white paper. Whatever comes into your mind, when the eyes are directed to the figure, is called a *mental content*. If you see only "black lines on the white surface" of the chart, the mental content is relatively simple. When the mental content is more complex, — for example, the perception of the drawing of a staircase, — the complexity is due not to the lines of the figure actually before your eyes, but to former perceptions of staircases, drawings, and similar objects that have been seen, touched, and handled. By virtue of this experience, the mind itself contributes more to the formation of the present perception than does the action

of the physical stimulus upon the sense organ. For this reason, the mind is said to *ap-perceive* the external object.

It is easier and more "natural" to perceive the figure of Chart 1 as a "staircase" than it is to see merely "black lines on white paper." In fact, we seem to perceive "the staircase" as immediately and instantaneously as we hear the sound of a bell or feel the heat of a stove. The mental contents with which we *react* or *respond* to the sound of the bell, the heat of the stove, and the black and white of the chart are the results of the *process of sensation*, a native or inborn capacity of every one possessed of normal sense organs and brain. The perception of "staircase," on the other hand, is only in very small part due to sensation. It is chiefly the product of a mental process, called *apperception*, that is formed and developed, through experience and education, during the life of each individual human being. This development is reflected more particularly in the acquisition of memories of former experience, and in the formation of new habits. In accordance with the character and number of these memories and habits, a mind reacts to a simple stimulus so as to form a complex mental content, called a *perception* of the object. Every perception is a *synthesis*, or combination, of the part contributed by apperception and the part contributed by sensation. What is received by the mind through sensation is always supplemented and elaborated by the *process of apperception.* The progressive growth and modification of each individual mind is called its *ontogeny*. Through apperception, therefore, is effected an *ontogenetic elaboration* of the simple mental contents that are the bare results of the stimulation of sense organs.

It is often difficult to demonstrate the contribution of apperception so as to distinguish it from that of sensation, because the completed perception usually seems to be an unanalyzable unit directly and entirely inspired by the stimulus. The experiment with the staircase figure makes this distinction clear.

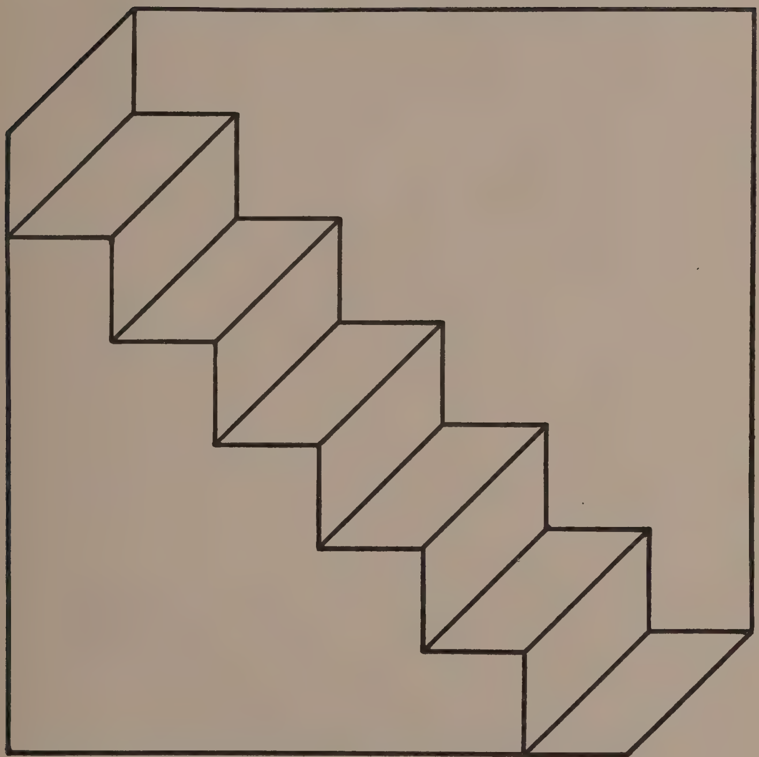


Chart 1

One and the same stimulus is shown to give rise to two different perceptions. This cannot be due either to the stimulus or to sensation, because the eyes and the brain are stimulated in each case by the same physical object. Neither perception is an illusion; "the staircase from underneath" is as true a perception of the lines as is "the staircase from above," although the latter perception is the more readily formed in many minds. A figure drawn without definite perspective, as are those upon which are based the first three experiments of this Manual, is called an *equivocal* figure, because the stimulus is not able to elicit decisively any one of the possible contributions of apperception. In consequence, your neighbor's mind may not react to a given stimulus with a mental content similar to yours, nor need your mind react at all times with the same perception; but all minds will manifest at all times an apperceiving tendency to supplement and elaborate, in some way, the mental results of the action of a stimulus upon the sense organ.

EXPERIMENT II. **A perception may be determined by the association of an anticipating mental image or idea of the object — *i.e.*, by preperception.**

Look again at the figure on Chart 1. Can you see this figure as a strip of cardboard extending obliquely from the upper left-hand corner to the lower right-hand corner, bent at right angles like an accordion plait, and situated in front of the plane of the apparent background? The outline of the figure will then give the perception of a continuous plane surface, a background, in front of which is suspended the plaited strip. Can you vary the angles of the plait, causing them to appear at will as either right, obtuse, or acute angles?

This perception of the figure is often more difficult to obtain than the "staircase" perceptions. It is therefore necessary to think vividly beforehand of what you expect to see. The

anticipation of a perception by a thought, idea, or mental image is called *preperception*. Some may be unable to see even the "staircase from underneath," until, through attention to what is expected to be seen, apperception is assisted by a vivid preperceiving image. It is important to distinguish *associated preperception* from apperception. When the words, "Do you see an accordion plait?" are seen or heard, they are associated with a visual image of the object indicated by the words. This visual image, due to the *reproductive process of memory*, is in turn associated with the lines on the paper as these may have been originally perceived, either as "lines" or as a "staircase." Through this associated preperceiving image, the simpler visual sense perception is supplemented and modified to correspond to the particular object of preperception.

When this new perception does find place in consciousness, it will seem to be as directly inspired by the figure, and as natural, as did the perception of "staircase." Associated preperception accomplishes the same final result in the formation of a perception as does apperception. When the "staircase from underneath" and the "accordion plait" perceptions are once obtained, it may be difficult to keep any one perception in mind to the exclusion of others; a continuous and unavoidable fluctuation from one perception to another will be observed. It appears from these experiments that the apperceiving tendency to react to the stimulus so as to form a perception of "staircase from above" is already perfected by most minds, whereas a similar tendency to perceive "staircase from underneath" or "plait" is developed only with the assistance of a preliminary association of definite and more or less vivid memory images. The perception of "staircase," which arose in mind at first sight without consciousness of any preceding associated image, is dependent upon an apperceiving tendency also originally developed from associated memories of similar perceptions. These memories, however, do not have conscious or psychical

existence at the moment of perception. Their influence in the past can only be inferred from the increased complexity of the present perception. Such modification of the apperceiving process as may be attributed to them is accomplished.

This growth and training of apperception through individual experience is somewhat analogous to a change in taste for some article of food. For example, one does not find the taste of olives agreeable at first, however acceptable they may subsequently become. No one will ascribe his acquired fondness for olives to associations with, or memories of, the first three or four that were eaten. The eating of olives develops little by little a mental tendency to react in a new way to the old stimulus, *i.e.*, with an agreeable taste sensation instead of with the former disagreeable one.

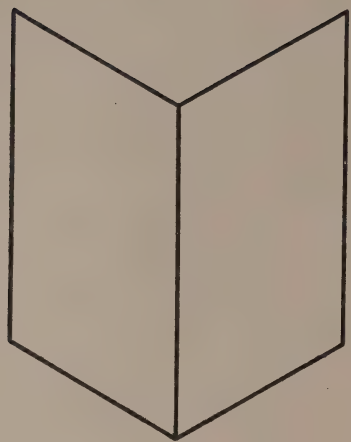
Every perception exhibits some degree of apperceptional elaboration. Suppose that two men fall within the field of your visual perception: the one is your father, let us say, and the other, a man whom you have met but a few times and, in consequence, do not at once recognize. You would describe the two perceptions in the words, "I see (perceive) my father," and "I see (perceive) a man." In the second instance, you may add: "I ought to know who he is; let me think where I have met him before. Why, his name is just on the tip of my tongue!" As you endeavor to place him within the circle of your acquaintance, you will reproduce visual and other memories of the occasions of your meeting him; his image will take its place in your mind along with the images of other persons; you will think of the person who made you acquainted with him; you will try to recall your conversation at the time. Suddenly the events with which he has been connected in your past experience stand out clearly in your mind. Recognition follows. His name is formed by the tongue. Thus these preperceiving memories, associated with your perception of "a man whom I ought to recognize but cannot," will

produce a new mental content to which you may give expression in such words or thoughts as, "That's the man I met at the railroad station; his name is Jones." If, in the future, he should become better known to you, the necessity for calling up and associating preperceiving memories will gradually diminish, and in the course of time you perceive "Mr. Jones" on sight. Associated preperception will then have been transformed, through development, into apperception.

The perception of "my father" is so immediate and so devoid of associated preperceptions that you would never say, "I see a man whom I remember to be my father." The apperception of "father" has its origin in the perceptions of the first years of life, a period of which you retain few, if any, definite memories. You do not perceive "father" by an association of the memories of either remote or recent experiences of your father. Experiences, too numerous and remote to be recalled, have developed the apperceiving tendency necessary to elaborate the result of that one stimulus alone, so as to form the particular mental content which you call the perception "my father."

Apperception is observed even in simpler perceptions, for example, in the perception "man." This perception is distinguished from that of "woman," or of "horse," or of "church," or of any other object, only through former experience of these objects. Yet the attitude of mind in perceiving "man" is not that of seeing some indefinite thing, which, by association with memories of men and other objects, is supplemented and transformed into the perception "man"; it comes into mind immediately, a completed and distinct perception. Even when the perception is restricted, say to the "red color" of his hair, the mental content, a color sensation, is partly the result of former experience of variously colored objects. A simple sensation, in the sense of a mental content absolutely unmodified by individual experience, does not exist except perhaps at the initial moment of conscious life.

a



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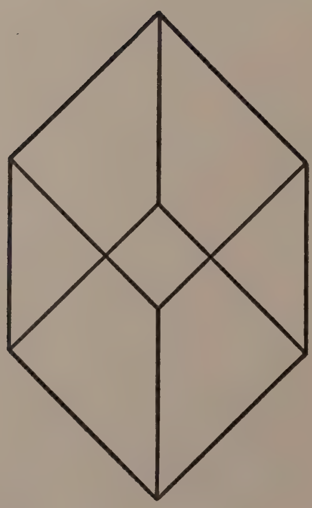


CHART 2

The student must be cautioned against confounding the terms "apperception," "perception," and "sensation," even though he cannot expect to obtain a clear understanding of their exact meaning at the outset of his course in psychology. Definitions alone will not enable him to comprehend fully the processes of mind to which these terms refer. The processes are so complex that it is possible, only by making him acquainted with the various phenomena of mind, to develop gradually the apperception necessary for their comprehension.

A physical stimulus, for example, a red color, gives rise to a mental content which the psychologist may call at one time a perception, and at another, a sensation. Thus the student will meet with the terms, "perception of red" and "sensation of red." Sensations are assumed to be determined entirely by the inborn activity of sense organs and sensory centers in the brain. Although it is appropriate thus to designate the simplest possible mental contents as sensations, it must be remembered that they may also be referred to as perceptions, whenever it is desired to emphasize the fact that even the simplest mental result of the stimulation of a sense organ is always, though in some cases only in small part, the product of the same mental process that is so clearly manifest in the more extensive apperceptional contribution to complexer contents. Indeed, if we wish to call special attention to the important rôle played by apperception and temporarily to exclude sensation from consideration, we may correctly say, "I apperceive the red color," as also, "I apperceive the man or my father." In general, therefore, perceptions are mental contents due to the joint activity of sensation and apperception. Sensations are the simplest perceptions relatively. They appear to be approximately unmodified by apperception, remaining, for the most part, as they were at the beginning of conscious life. They may exist in mind either as single and discrete mental contents or as the combined and component parts, called *elements*, of more complex contents.

Another source of possible confusion to the student is the use of the term "perception" to designate both the mental content and also the process by which the content is determined; thus in the sentences, "I have a distinct perception of a church" (content), and, "It is through perception that we get our knowledge of the external world" (process). Some psychologists use the term "percept" for the content, and restrict the term "perception" to designate the process. In this Manual, "perception" usually means the content; whenever the process of perception is implied by the context, it is intended to refer to the joint activity of sensation and apperception, and not to a third process distinct from these. The term "sensation" will be employed, as may be required by the context, to designate either the process or the mental content.

EXPERIMENT III. **The apperceptional contribution in the perceptions of equivocal stimuli.**

A. Can you see Fig. *a*, Chart 2, bent at an angle directed either toward you or away from you?

B. In what two different positions can you see the cube, Fig. *b*, Chart 2?

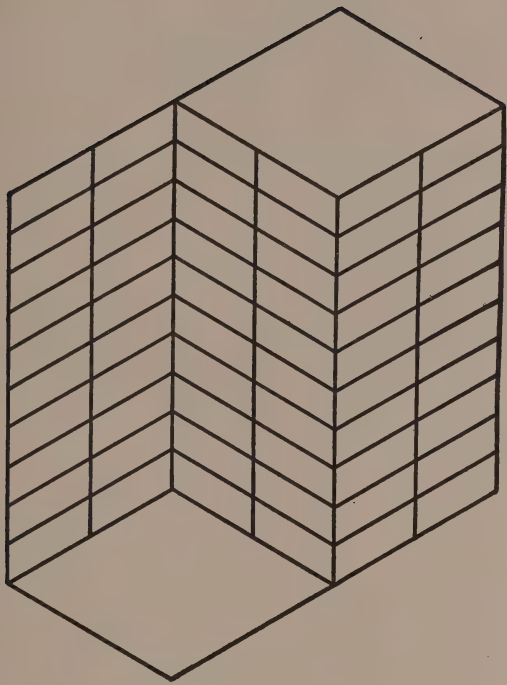
C. Observe the rapid and incessant fluctuations in the perception of Fig. *a*, Chart 3.

D. Observe in Fig. *b*, Chart 3, that the repeated pattern seems now to recede, now to advance. Can you keep the repeated elements for any considerable time in the same plane? Have you ever observed similar fluctuations in wall paper or dress patterns?

E. Are there six or seven blocks in Fig. *a* of Chart 5?

Is the cause of these fluctuating perceptions to be ascribed to the figures, to apperception, or to associated preperception? Do the figures give rise to the perceptions of objects having a spacial quality, *i.e.*, depth or solidity, not possessed by the figures themselves? Describe, in each case, the apperceptional contribution which makes the perception more complex than its stimulus.

a



b

CHART 3

Experiment IV. **Variable and individual apperception.**

A. Observe either a duck or a rabbit in Fig. *a* of Chart 4.

B. Describe Fig. *b*, Chart 4. You may see a six-pointed star; a hexagon with a triangle constructed on each side; two superimposed triangles, etc.

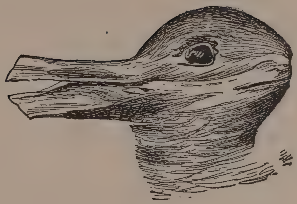
C. Describe Fig. *c*, Chart 4. The sixteen crosses may be perceived as four horizontal rows of four each; four vertical rows of four each; a square of four on a side, enclosing a square of two on a side; four squares of two on a side, etc.

D. What are your perceptions of *b* and *c* of Chart 5?

E. Observe intently for some time *d* and *e* of Chart 5. Are you able to form perceptions from these indefinite stimuli?

F. Do you ever see various forms or faces in the flames of an open fire, in the clouds, in wall-paper patterns, or in the arrangement of tea grounds in the bottom of a cup?

The perceptions to which some of these figures give rise will appear to have been constructed by a fanciful play of the imagination rather than by apperception or associated preperception. Fancy or imagination, however, does not differ fundamentally from memory; both involve a reproduction of the elements of past experience. Memory images reproduce with considerable fidelity former perceptions; the images of fancy are more unusual and accidental, but nevertheless their component parts are never absolutely foreign to past experience, no matter what oddities their combination may present. Still other and characteristically different mental contents, which are appropriately described as ideas, thoughts, or concepts, may have been observed associated with and transforming the perceptions of these figures. Ideas are also developed through individual experience and are given actual existence in a mind by the reproductive process. Of all the mental contents that may be associated with a perception so as to perform the function of a preperceiving image, those due to fancy vary most for different minds and for the



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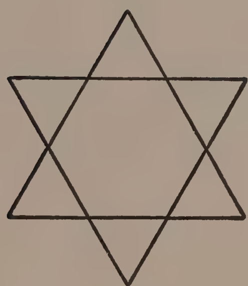

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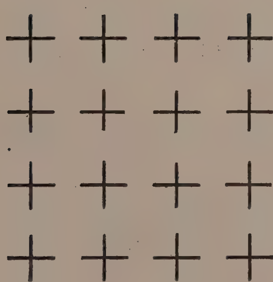


c

Chart 4

same mind at different times; they seem, in consequence, to be least directly inspired by the stimulus.

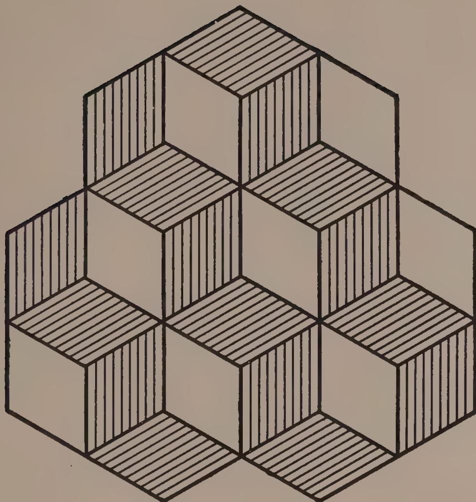
In some cases, there will have been associated with a perception either ideas or images of memory and fancy, which remain discrete accompaniments of the original perception without transforming it into a new perception. Thus a cloud remains a cloud, although associated with the suggested fanciful image of some animal. In this and similar cases, the stimulus gives rise to a perception which starts into existence one or more associated contents due to the reproductive process. This mental situation is very different from that brought about by such figures as the staircase and the seven cubes. The latter figure, for example, does not call up a perception of six cubes which has associated with it a memory image of seven cubes; the stimulus calls up each of the two perceptions directly and each perception momentarily excludes the other.

These experiments have served to show that the mind may react to a stimulus with one of three different results. These are: (1) a perception, the product of apperception and sensation; (2) a perception due to sensation primarily, but transformed through an association of preperceiving images contributed by the reproductive process of memory, fancy, or thought; and (3) a perception, which is formed either as 1 or 2, accompanied or followed by other mental contents contributed by the reproductive process and thus initiating a train or series of associations.

Experiment V. **Constant and universal apperception.**

A. Are the rings on Chart 6 complete and interlaced, or are they broken rings laid carefully together? Is not the latter more nearly what is represented by the figure? Is not the figure in reality composed of a number of broken curved lines? Why are you compelled to see complete interlacing rings?

B. In Fig. *b*, Chart 6, does the column appear to pass in front of



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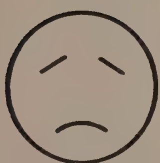

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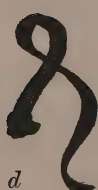


d

e

Chart 5

the arch? Is it not unnatural to see the arch broken and interrupted by the column, and yet, so far as the figure itself is concerned, might not the lines of the arch and column be in the same plane?

We have repeatedly seen objects near us obstructing the perception of other objects beyond them. This has formed apperception so as to make possible and natural the one perception of the arch and column as though they were situated at different distances or depths in front of us.

C. Observe the size of a book lying on the table within reach. Move the book to the middle of the table and then to the opposite edge. Does the book appear to change in size? What change has taken place in the size of the retinal image?

Have you ever observed, from a great elevation, men and animals, and other well-known objects? Why do they appear so small?

The diagram on this page is designed to illustrate the relative size of an object and its *image* formed upon the inner posterior surface, called the *retina*, of the eye-globe. Let the arrow

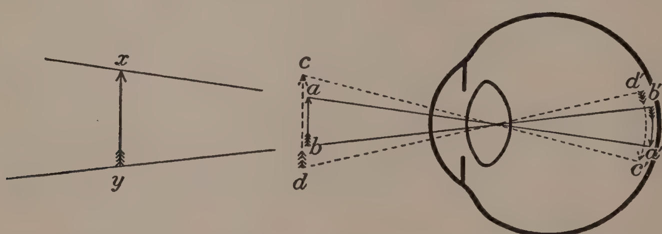
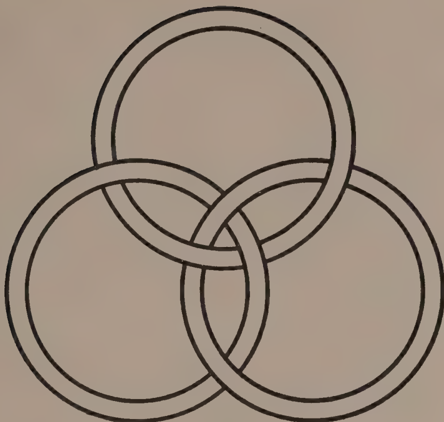


DIAGRAM I. The relative size and inversion of the retinal image.

ab represent any object capable of affecting the sense organ of vision, and let $a'b'$ be the image of that object upon the retina. The lines aa' and bb' represent the rays of light reflected from the extremities of the object, passing through the lens, and crossing before they reach the retina. Between these lines extended into space outward from the eye, we can draw at any



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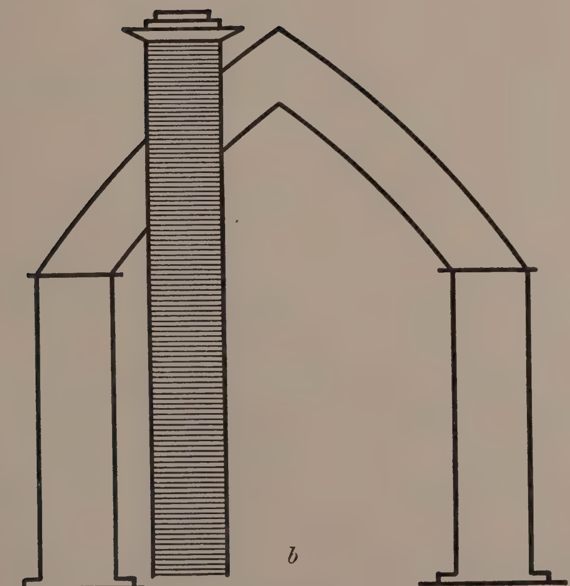


b

CHART 6

distance from the eye another arrow, for example, xy. As the ray lines from the extremities of xy, i.e., xa' and yb', coincide within the eye with those from the extremities of ab, the retinal images of xy and ab will be of the same size, although ab is smaller than xy. Conversely, the same object at different distances from the eye will cast images of different size upon the retina. Thus the dotted arrow cd, equal in length to xy, at the position of ab, casts upon the retina the image $c'd'$, larger than $a'b'$, which represents the size of the image cast by the same arrow at the position of xy.

If a book, as suggested by this experiment, is seen first at a distance of say two feet from the retina and then at a distance of six feet, the retinal image of the book in the first position will have three times the length and breadth of the image of the book in the second position, and nine times the area. Our minds must modify what is received through the retina, or the book would appear to grow rapidly smaller as it is moved away from the eye. The knowledge of the actual size of an object would seem to be more effective in determining the perception of the object than the changing retinal images.

This apperceptional modification of sensation is constant and universal. It requires some unusual distance, as a great elevation, producing a very considerable diminution in the size of the retinal image, to overcome the tendency to elaborate the simple mental result of a stimulation of the retina into a perception of the object as actually known to us.

It will be observed that the diagram represents the retinal image inverted, relative to the position of the external arrow. This inversion is due to the refracting properties of the lens. How is it that we see objects right side up, if their retinal images are thus upside down? This question is puzzling only so long as we fail to recognize the significance of apperception in determining the perception of objects. *We see the object*, i.e., *the arrow, not the retinal image of the arrow.* No one is ever

aware of what is going on in the retina when he is in the act of perceiving an object. It is true that we perceive the arrow by means of the retinal image, but we perceive it likewise by means of the optic nerve and brain. There are no images in the nerve, nor yet in the brain. Moreover, the physiological processes are such that "right side up" and "wrong side up" do not apply to them. As the size of the retinal image is relatively unimportant in determining the perceived size of the object, so also is the spacial inversion of the image. "Right side up" is the customary upper side for perception. The habitual mode of perception is dependent upon more extensive experience of the object than is gained from the visual sensations due to the retinal image; for example, upon our walking to and about the object, handling it, etc. The retinal image changes with every movement of the body, head, and eyes, but in the course of mental development repeated perceptions have established the tendency to perceive an unchanging object of constant size and position. Experiments in Chapter IV will present the more important features of this development of space perceptions.

Experiment VI. **An associated preperception may produce an illusion or false perception.**

A. Bend a card (a visiting card will do) so as to enclose an oblique angle. Stand the card upon its edge with the fold vertical and directed away from you, so that you will be looking into the concavity formed by the bent sides of the card. Place the card on a table in such position that no marked shadows are cast across either side of the concavity. Stand about a yard away from the card, looking somewhat downward into the concavity. Strongly imagine the two sides to be bent in just the opposite way, so as to form a convexity; to do this, think the vertical line of the fold to be nearer than the edges of the card. You will find that you can make the card appear either convex or concave at will. The former

perception will be an illusion, the latter will correspond to the external real object. Turn the card about, so that the convexity will be directed toward you. Can you see the sides of the card to be concave?

This experiment is somewhat similar to Experiment III, A, but in the present case the spacial relations of the parts of a real object are apparently changed. This is therefore an illusion — a false perception — whereas Fig. *a*, Chart 2, offers a choice of two perceptions of an equivocal figure, neither perception being false to the real conditions of the stimulus.

B. Get three boxes (pill boxes or bottles will do) of marked difference in size, but, if possible, of the same shape. Place in each box some small shot or sand so that the three boxes are of exactly the same weight. Fill the boxes with cotton or any material that will keep the shot or sand from moving about. Lift the boxes and observe the apparent difference in weight.

The smallest box will seem to be the heaviest, and the largest box the lightest in weight. This illusion in weight is due to: (1) the visual perception of the actual difference in size; (2) the fact that large things are usually heavy and small things light — which has given rise to an apperceiving tendency that causes us to perceive the large box as heavy, before we lift it, and the small box as light; (3) the contrast between the preperceived weight (very heavy or very light) and the actual weight of the box (medium), which causes the preperceived "heavy box" to seem lighter than the box of medium weight, and the preperceived "light box" to seem heavier.

C. *The measurement of the amount of this illusion.* Take a very small and a very large flask, bottle, or box. Fill the smaller one with shot so as to be of considerable weight. Require the subject (the person upon whom the experiment is made) to fill the larger one until it is judged by him to be just equal in weight to

the smaller. Weigh the larger and record the amount by which this exceeds the smaller in actual weight.

To determine whether the subject is constant in his overestimation of the weight of the small box, repeat this experiment four times, so that you will have five different records of the amount of overestimation. The amount will probably not be the same in the five trials. Add the five quantities together and divide by 5 to get an average result. Then find the amount by which each of the quantities differs from the average result. These will be the variations of each of the five trials from the average of the five trials. Add these variations and get an average variation.

In making this experiment, in one case, a four-ounce Florence flask loaded with shot to weigh two hundred grams was compared by the subject with a much larger glass battery jar filled with sand. A student's record of this experiment showed that the larger object was estimated equal to the smaller when its actual weight was in excess of the smaller:

On first trial by	250 grams
On second trial by . . .	153 grams
On third trial by	167 grams
On fourth trial by . . .	189 grams
On fifth trial by	142 grams

The following table shows the method of treating these five results to get an average result and average variation.

Number of the trial.	Difference in weight.	Variations from average result.
1	250	(250 – 180 =) 70
2	153	(180 – 153 =) 27
3	167	(180 – 167 =) 13
4	189	(189 – 180 =) 9
5	142	(180 – 142 =) 38
	5|901	5|157
	Average = 180 grams.	Av. var. = 31 grams.

The average result measures the amount of the illusion, and the average variation measures its constancy. The larger the

a

We the poeple of the Uuited States, in order to from a more perfrect union, estadlish justise, insure domastic tranpuillity, provide fore the comnon defence, promote the ganeral wellfare and secrue the blesings off liberty too ourselves and onr postreity, do ordian and establish this Constitntion for the Uniteb States of America.

b

1. transcendental rehabilitate circumstance
2. appreciation philosophize illumination
3. charitableness notwithstanding alliteration
4. bibliographical mineralogy furthermore
5. immediate reduplication immutability
6. experiment continental cosmopolitan
7. effectiveness adaptability regeneration
8. architecture technological philanthropist
9. mismanagement superintendent separately
10. communicate investigation relativity
11. illustrious thoroughness interlinear
12. superimpose physiological consequence
13. psychology satisfactory respiration
14. mechanism application constructive
15. indication transformed insensible
16. alienate unnecessary permanently
17. unfavorable development conversation
18. spontaneous irritable appearance
19. constriction individual apperception
20. proportion association constitution

Chart 7

average variation, the less significant is the average result as the expression of a tendency to overestimate by a constant amount the weight of small objects with reference to that of large ones. A large average variation may lead one to suspect carelessness on the part of the subject or experimenter, ignorance on the part of the subject as to what was expected of him, or a real uncertainty in his judgment due to want of practice or some other cause. It cannot be expected, however, that judgments of the amount of this illusion will be very constant, for the conditions of the experiment make the preperception necessarily variable.

Experiment VII. **Apperception may produce an illusion.**

A. Read the preamble of the Constitution of the United States as printed on Chart 7, and count the number of errors discovered. Go over the selection a second time, examining every letter carefully. What is the total number of errors?

The failure to observe an error demonstrates that the tendency to apperceive words as they would appear when correctly printed is strong enough to modify the perception received from the word as it is really printed.

B. Let a number of students or other persons (the subjects) be prepared to write down words at dictation. Let the experimenter (a student or the instructor) call out distinctly, but without unusual emphasis, the following words and nonsense syllables: cat, hog, fif, log, mere, pod, jug, ind, han, seef, there, a, sos, where, sod, mud, hub, than, neg, trite, stro. In what different ways do the subjects apperceive these simple auditory stimuli?

If the subjects have seen these syllables, preperception may cause them to be correctly apprehended; in this case, the experimenter should prepare a new series.

Experiment VIII. **The facilitation and development of apperception.**

Cut from a sheet of paper or thin cardboard a rectangular slit $\frac{1}{8}$ inch wide and $2\frac{3}{4}$ inches long. Let the experimenter place this sheet over the words of Chart 7, *b*, so as to expose at one time only the three words in the same horizontal line. Place the chart before the subject with the words in easy position for reading. Let the subject read aloud the words thus exposed. Move the sheet so that a new line of words is exposed to view. Do not let the subject see these words; hold a piece of cardboard just above the words to screen them from his gaze. Direct the subject to prepare to read, as quickly as possible, the words that will be exposed to view when the screening card is removed. Remove the card for a moment only. Require the subject to write the words or letters he has seen. If he has failed to give all the words actually exposed to his view, remove the screening card a second time for a moment only. Require him to write, in order, the words or letters now seen. Repeat this procedure until the subject is able to perceive, on momentary exposure, the three words. Try with the three words of ten different lines. Determine the average number of exposures necessary to form a correct and complete perception of three words.

The training of apperception, which has been accomplished through the ordinary school instruction in reading, makes possible the perception of a limited number of words, or parts of a word at least, on a very short exposure. When the same words are momentarily exposed for a second time, apperception is assisted and facilitated by the former incomplete perception of the words. The apperceptional tendency to perceive words in general has become an apperceptional tendency to perceive particular letters and words. In the facilitation of apperception, thus made evident by the greater number of letters and words comprised in the perception received from a momentary exposure, is illustrated the usual course of the development of apperception through repeated experience.

CHAPTER II

ATTENTION

Experiment IX. **Preperception increases the perceptibility of threshold stimuli.**

A. *Auditory stimulus.* Let the subject, seated in a quiet room, keep the head steady and the eyes shut. Hold a watch, that has not been seen or heard by the subject, at a distance of at least three yards, straight out from his right ear, *i.e.*, at a right angle to the median vertical plane of the head. Move the watch slowly and steadily toward the ear. Require the subject to give a signal as soon as he hears the faintest ticking of the watch. Stop when this point is reached and measure the distance with a yard-stick or tape. It is convenient to have two experimenters, one to hold and move the watch, the other to measure and record the distance. Make three trials and average the three results.

Let the subject now listen attentively for some seconds to the sound of the watch held close to the ear. Then determine, as before, the average maximum distance of three trials. Is the distance greater or less than that obtained before the subject became familiar with the sound of the particular watch employed?

The greater the distance of the watch from the ear, the less is the intensity of the stimulus of sound when it reaches the ear. The distance at which the ticking watch can be heard will be greater in the second set of experiments than in the first, because the memory of a sound sensation just heard is more vivid and definite, and therefore more effective, than remote and less definite memories of the sound of watches. Even in the first set of three trials the second trial should give a greater

distance than the first, and the third a greater distance than the second. This increase in the distance is due to the effect of practice, which, by developing a more definite memory image, makes preperception more effective in reducing *the threshold of sensation*, *i.e.*, the intensity of a stimulus just sufficient to give rise to a simple mental content. The mental preparation for a particular stimulus is the important feature of *expectant attention.*

The expression "threshold of sensation" is a figure of speech based upon the following thought. The mind is like a house, outside of which are the physical stimuli. Weak stimuli cannot cross the threshold of this figurative house of the mind to excite sensation. The threshold may be high or low. Expectant attention lowers the threshold and thereby allows a stimulus, which would otherwise remain below the threshold, to give rise to sensation. A stimulus strong enough to awaken a vague sensation may be too weak to be distinctly perceived and discriminated. We can therefore distinguish various thresholds of complex perception and discrimination; these are generally higher than the threshold of simple sensation.

B. *Visual stimuli.* Take five sheets of paper and make a different mark or sign of equal size and distinctness upon each, — *e.g.*, a cross, a circle, a square, a triangle, etc. Fasten each of these sheets in succession to the wall or blackboard at such distance from the subject that he cannot tell whether the sheet is marked or not. Do not let the subject know what marks he is to expect. Let the subject move toward each of the five sheets in succession and report (1) when he sees that there is something on the paper and (2) when he distinguishes and recognizes the mark. Measure the distances. Record the two results for each of the five different marks and get the average distances at which the five marks can be respectively (1) perceived and (2) discriminated.

Repeat these experiments, but let the subject examine the mark on the sheet before each trial. Do the results show that preperceptional

attention has increased the distance at which perception and discrimination are possible, or, in other words, has it lowered the respective *thresholds of perception and discrimination?*

EXPERIMENT X. **Attention involves the adjustment of a sense organ as well as the mental preparation for a particular stimulus.**

A. *Auditory stimulus.* Begin with the watch close to the subject's right ear. Move the watch away from the ear along the same line as in Experiment IX. Require the subject to announce when he ceases to hear the ticking watch. Make three trials and average the results. Is the distance greater than in Experiment IX, A? Why?

B. *Visual stimuli.* Use the same cards as in Experiment IX, B. Let the subject first stand at a short distance from the card, and then move to a position where he fails (1) to recognize the mark, and (2) to perceive that there is any mark upon the sheet. Average the results of the trials with each of the five cards, and compare the two averages with those obtained in Experiment IX, B.

The distance at which a threshold stimulus can be perceived and discriminated will be greater in this experiment than in Experiment IX. The sense organs of hearing and seeing, respectively, are adjusted to the actual stimulus, whereas through expectant attention they can be only imperfectly adjusted. Moreover, a continued perception is more effective in retaining the mental content received from a minimal stimulus than is preperception in assisting to form such content. To attend to a perception that is about to be received requires a memory image of what is expected and a general adjustment of the sense organ. To attend to an actual perception involves the activity of apperception and the perfect adaptation of the sense organ to the particular stimulus. Attention increases the mental result of a stimulus through apperception and the voluntary control of the muscles that take part in the adjustment of the sense organ.

EXPERIMENT XI. **The relation of attention to apperception.**

A. Think of sheep jumping over a fence. How long can you keep your attention fixed on this mental picture? How do you bring your attention back to the image when it seems to turn to other ideas, perceptions, or sensations? How do you know that you are attending to the mental picture called for?

B. Place a watch where you can readily hear it ticking. Attend exclusively to this sound for three minutes. Describe what took place in your mind during the period of attention, making particular note of the effect of distracting stimuli, possible sensations of strain in the ear, the position of the head, etc.

C. Describe the order and character of the phenomena when your attention is suddenly directed to a very loud noise, a band of music, or other attractive stimuli. How is this involuntary attention distinguished from the voluntary attention of A and B?

The same mental content will, at different times, vary in distinctness and vividness. At any one moment some of the contents of consciousness will be more distinct and vivid, and others less so. A mental content which is distinguished from others by its greater vividness or distinctness is said to be *attended to* or to *receive attention.* A mental content is said to receive less attention when it loses somewhat in vividness and distinctness as other contents, from whatever cause, increase relatively in vividness. The number of contents that can receive attention is so limited, that a new perception necessarily diminishes the attention or perceptual vividness of those already in mind, and may indeed be the cause of their dropping out of consciousness entirely. Maximal attention to any one mental content is not possible for a great length of time; even within short periods of time, attention fluctuates. The maximum of attention seems to be attained at intervals of two or three seconds; the mental content, therefore, periodically waxes and wanes in vividness.

In the previous chapter, the existence of a perception was shown to be determined both by sensation and apperception. A fluctuation in the vividness of a perception may, therefore, be due to variations in either process. When attention is directed to an external object, the adjustment of the sense organ is an important factor in determining which of a number of stimuli shall receive attention. The adjustment of one organ inhibits or makes more difficult the adjustment of another organ for the reception of stimuli, and the adaptation of a sense organ for one stimulus will make it less capable of reacting to other stimuli. A stimulus may, therefore, produce a vivid perception merely because of its own intensity and the adequate adjustment of a sense organ. And yet, at times, even vigorous stimuli fail to dispossess the mind of perceptions and ideas, in themselves less attractive. Thus the scholar may "absent mindedly" (really through maximal attention) continue to work out a problem in mathematics despite the ringing of fire-bells, which would gain every boy's attention. The perception of an external object with attention requires the contribution of apperception to be as vivid as possible. The content obtaining the most considerable or most vivid apperceptional contribution will be the one to receive most attention. In proportion to the vividness of apperception awakened by other stimuli, attention will be withdrawn or distracted from a given mental content, as, for example, the "sheep" or "watch." Making strokes with the pen automatically will not be so distracting as writing words from dictation, reading, or performing some simple mathematical problem. The most distracting stimuli will perhaps be music, or the reading of an emotional poem, because these make numerous and many-sided appeals to apperception and thereby receive the contribution necessary to form vivid perceptions.

The various factors determining the formation of a perception with attention are: (1) the relative intensity and mode of application of the stimulus; (2) the adjustment of the sense

organ; (3) preperceptions increasing the vividness of the perception with which they are associated; (4) emotional interest, including pleasure and pain, which also contributes to the vividness of associated contents; (5) apperception.

All these factors are usually concerned, though in different degrees, in the production of attention. But, at times, one or another factor may have a preponderating influence. For example, a very loud noise acting upon the sense organ of hearing precludes choice. The adjustment of the sense organ follows directly upon the stimulus, which thus gains apperception and consequent attention of its own energy. Such a stimulus is said to be passively perceived, and its existence in consciousness with maximum vividness is the state of *passive attention.* If two or more stimuli of nearly equal attractiveness in themselves give rise to perceptions, choice is possible; the selection of the content to be given attention is then related neither to the sense organ nor to the stimulus, but to the apperceptional conditions described in previous experiments. The adjustment of the sense organ follows upon some controlling idea, memory image, or perception; a familiar illustration of this is the turning of the head and eyes toward an object about which one may be talking or thinking. The conscious adjustment of a sense organ may be either voluntary or involuntary, depending upon the manner in which the conscious antecedent of the movement comes into mind. When a given mental content is retained in consciousness for some length of time, as, for example, the sound of the watch, the voluntary effort necessary to keep the sense organ adjusted to the particular stimulus is distinctly observed. The will is closely related to apperception, because the production of a voluntary movement requires the apperception with great vividness of those ideas which initiate the various movements of the body. The attention which results directly from the selective activity of apperception is appropriately designated *voluntary or active attention.*

EXPERIMENT XII. **The relation of attention to physiological adjustment.**

A. Stand before a mirror and cover both eyes with the hand. Remove the hand suddenly and look at the pupils. Observe that they are rapidly contracting. To observe this contraction in the eye of a subject, cover the eye for a few moments with the palm of the hand and then suddenly uncover; or bring a lighted match near to the subject's eye; or slowly darken the eye by covering with the hand and observe the gradual change in the size of the pupil.

B. Stand as before in front of a mirror at a distance of two feet; move the head slowly toward the mirror, keeping the gaze fixed upon the pupils. Observe that the pupils contract as the eyes approach the mirror and expand as they recede.

To try this with a subject, hold up the forefinger of the right hand before the subject's eyes, requiring him to fixate the finger. Move the finger toward the eyes until within a distance of a couple of inches, and then move it off to a distance of fifteen or twenty inches. The pupil will be seen to contract as the finger moves toward the eye and to expand as the finger moves away. Hold a book directly in front of the face of the subject at a distance of four inches, and another book at a distance of twenty inches. Observe that the pupils change in size as the subject's gaze turns from one book to the other.

This contraction and expansion of the *pupil* is called the *pupillary reflex.* The pupil is a circular opening in the *iris* (the colored part of the visible eye), through which the rays of light pass to the interior of the eye-globe. The pupil appears black, because the observer is looking through a small opening into a dark inner chamber. The pupil is constantly changing in size, varying from one to eight millimetres in extreme diameters. The size of the pupil, and in consequence the amount of light admitted, is determined entirely by the size of the iris. This is controlled by two sets of muscle fibres, which are the essential structures of the iris. The *radiating* fibres are indicated in

Diagram II on this page by a few lines running in the direction of the cross-section of the iris. They radiate from the inner circular edge of the iris to its outer border. When these fibres

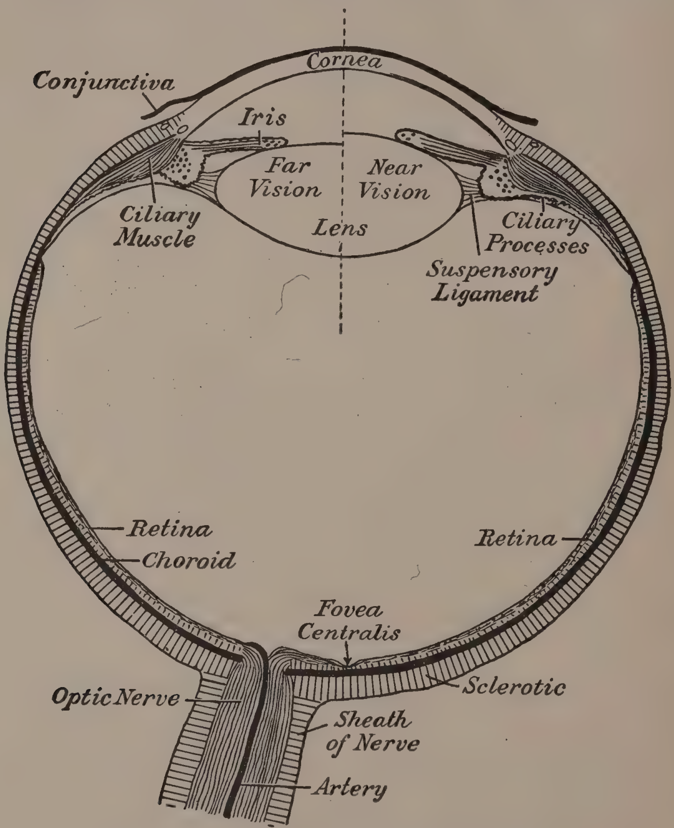


DIAGRAM II. The essential structures of the eye.

contract, they pull the inner edge of the iris outward, along all its radii, and so contract the iris and enlarge the pupil. The small dots at the inner edge of the iris (see Diagram II) represent the cross-section of fibres that extend in the form of a circle close to and about the inner edge. When these *circular* fibres

contract, they draw the edge of the iris together, and thus expand the iris and contract the pupil. The size of the iris is regulated by these muscles in proportion to the amount of illumination and also with reference to the distance of the object for which the eye as an optical instrument is otherwise adjusted. The contraction and expansion of the pupil are not under voluntary, or even conscious, control. Thus a part of the external preparation of the sense organ for the reception of a stimulus is a *physiological reflex adjustment* of the muscle fibres of the iris.

C. Hold the forefinger of the right hand at a distance of two feet in front of the face. Keeping the gaze steadily fixed upon the finger, move it toward the eyes until it is within a distance of two or three inches. Do you notice a feeling of increasing strain from the eyes as the finger approaches the face?

The feeling of strain as the object moves nearer to the eyes is a *kinaesthetic*, or *muscular*, sensation. This arises from the contraction of the muscle of each eye which adjusts the lens to the distance of the object, and of the muscles controlling the position of the eyeball in its socket.

The diagram on the opposite page represents the more important structures of the eye. The eyeball is nearly spherical and about one inch in diameter. It is covered in front by the delicate and transparent *conjunctiva*, which is a continuation of the skin of the eyelid. The eyeball proper is composed of an outer opaque elastic membrane, called the *sclerotic* (the white of the eye). In front, its place is taken by the transparent *cornea*, which protrudes like the crystal of a watch from the surface of the globe. The *choroid* membrane extends over most of the inner surface of the sclerotic (represented in the diagram by a heavy black line). At a short distance from the junction of the sclerotic with the cornea, the choroid separates from the sclerotic and forms two processes, the *iris* to the front, and the *ciliary*

processes or *folds*, which extend forward and toward the central axis of the globe to be connected with the *suspensory ligament* attached to the outer edge of the *lens* and holding it in its place. The sensitive portion of the eyeball is the *retina*, a thin membrane spread out over the inner surface of the choroid almost to the place of origin of the ciliary processes. The cavity between the cornea and the lens, the anterior chamber, is filled with aqueous humor; the posterior chamber, bounded by the lens, the suspensory ligament, the ciliary processes, and the retina, is filled with vitreous humor. The substance of the aqueous and vitreous humors is highly transparent.

The adjustment of the sense organ of vision requires an *accommodation*, as it is called, of the lens to the distance of the object, so that rays of light coming from the object may be brought to a focus on the retina. This is accomplished through the *ciliary muscle*, which, as shown in the diagram, is made up in large part of fibres attached in front to the cornea, at its place of junction with the sclerotic, and behind to the choroid. As these fibres extend like a girdle or collar about the anterior and inner surface of the eye, they are called *meridional* fibres. The dots adjacent to the meridional fibres, but nearer to the lens, represent the cross-sections of *circular* fibres. When these two groups of ciliary fibres contract, they pull the anterior edge of the choroid together and forward. The lens is held in place by the suspensory ligament, which is attached to the ciliary processes of the choroid. The natural elasticity of the eye-globe exerts, through the ligament, a continuous outward pull upon the circular edge of the lens. When this tension is released, the lens hangs more freely in place, and, owing to its own elasticity, the anterior surface (to a small extent the posterior surface also) becomes more convex. The diagram represents the right half of the lens adjusted for near vision. This is accomplished by the contraction of the ciliary muscle, which releases the strain exerted by the ciliary processes and

ligament upon the lens, thereby permitting it to assume its natural form of greatest convexity. The left half of the lens is represented as though adjusted for far vision. The ciliary muscle is not contracted, and the eye-globe exerts its tension outward through the ligament upon the lens, the lens in consequence being flattened.

D. Fasten the gaze steadily upon the first finger of the left hand, which should be held directly before the face. With the gaze still fastened upon this finger, move the right hand, with the forefinger extended, toward the left hand, beginning from a position to the right of the ear where it cannot be seen. Observe when the forefinger of the right hand is first seen as it crosses the edge of the field of vision. Move the finger of the right hand about and observe that it is more clearly distinguished at the border of the field of vision when moving than when at rest.

Observe how close the two fingers must be brought together in order that both nails may be clearly distinguished. While the gaze is still fixed upon the forefinger of the left hand, attention may be directed either to the nail of the forefinger of the right hand or to the nail of the forefinger of the left hand. Without moving the eyes, give attention alternately to the two nails.

Observe in all these experiments a difficulty in holding the eyes fixed upon the forefinger of the left hand, owing to what seems to be a tendency of the finger of the right hand to pull the eyes toward it. Do the movements of the eyes appear to be voluntary or involuntary at such times?

The innermost membrane of the eye-globe, the sensitive retina, extends, as shown in Diagram II, over more than one-half of the posterior inner surface of the globe. The retina is not equally thick in all portions, diminishing from .5 millimetre at the more posterior and central portion to .1 millimetre at the peripheral edge near the beginning of the ciliary processes. At the center of the retina is the *macula lutea*, or *yellow spot*, about one to two millimetres in diameter, in the center of which

is a depression, the *fovea centralis*, from .2 to .4 millimetre in diameter. All portions of the retina are not equally sensitive to light. From the fovea centralis, where the most distinct vision is attainable, the sensitivity of the retina diminishes

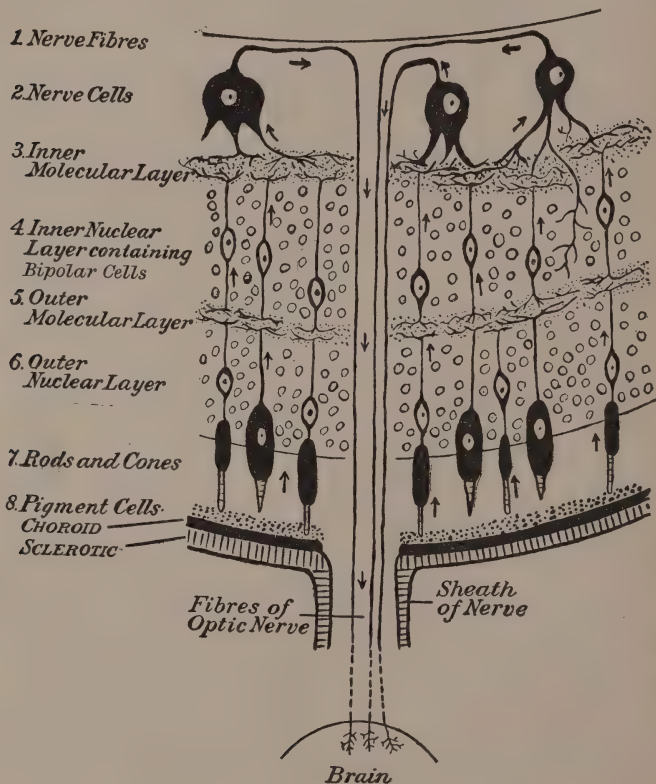


Diagram III. A microscopic view of the posterior part of the eye-globe, showing the sclerotic, the choroid, the eight layers of the retina, and the optic nerve as it breaks through the retina, choroid, and sclerotic on its way to the brain. The upper part of the diagram is directed toward the center of the eyeball. Rays of light must pass through six layers of the retina before they can stimulate the rods and cones. The arrows indicate the course of the physiological excitation, from the rods and cones, through the bipolar cells of the inner nuclear layer, to the nerve cells, thence to the nerve fibres, and thus to the brain.

toward the peripheral edge. The retina is composed of several layers of different microscopic structures, represented in Diagram III. This diagram presents, without attempting to reproduce relative dimensions, a section of the posterior part of the globe, showing the sclerotic, the choroid, and the various layers of the retina. Proceeding from the choroid inward toward the center of the globe, there is found in order a layer of pigment cells, a layer of visual rods and cones, an outer nuclear layer, an outer molecular layer, an inner nuclear layer, an inner molecular layer, and a layer of large ganglion cells from which nerve fibres run, as the innermost layer of the retina, toward a point where they are collected into a single bundle of fibres which turns at right angles and breaks through all the layers of the retina, the choroid and sclerotic, to emerge from the eyeglobe as the optic nerve. In all these layers, the only structures that appear to be directly stimulated by light are the pigment cells and the *rods and cones.* The rods are more numerous than the cones, except in the fovea centralis, where only cones are found. The fovea centralis is also marked by the absence of most of the other layers, from which results its characteristic pit-like appearance. The greater distinctness of vision from the fovea centralis seems to be due both to the presence of the cones and to the thinness of the inner layers. Rays of light can thus more effectively act upon the cones. The physiological excitation of the rods as well as of the cones is propagated from their inner branching terminals, through the bipolar cells of the inner nuclear layer, to the large ganglion cells, from which it is conducted by the fibres of the optic nerve to the brain.

A stimulus will give rise to more distinct and intense sensation if it acts upon the cones of the fovea centralis than if it acts upon the visual elements of more lateral portions of the retina. The more intense the process of sensation, the more likely is the stimulus to gain apperception and attention. The perception of an object acting upon the fovea centralis exceeds

so much in vividness the perceptions of objects acting upon other portions of the retina, that the latter perceptions are ignored, excepting under unusual conditions, and the former alone receives attention. When the rays of light coming from an object are focused within the fovea centralis, a line passing from the fovea centralis through the lens to the object is called the *line of sight.* To give visual attention to an object, therefore, is to turn the eyes so as to direct the lines of sight of both eyes upon the object.

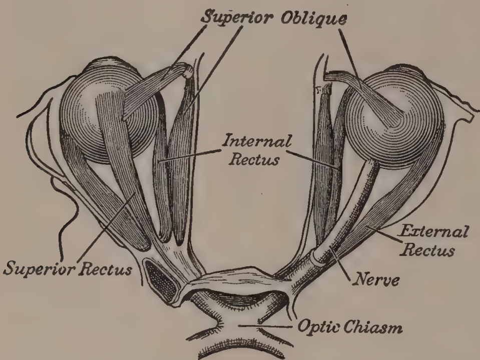


Diagram IV. View of the muscles of the two eye-globes from above, showing also the nerve of the right eye and the optic chiasm where some of the fibres of each nerve cross to the opposite side.

The movement of the two eye-globes necessary to accomplish this result requires that the respective contractions of twelve muscles be exactly proportioned and coördinated. Of the six muscles controlling the movements of each eye-globe, four are *recti* or straight muscles and two are *oblique* muscles. In Diagram IV is shown the superior *rectus* of the left eye, the *external and internal recti* of both eyes, and the *superior oblique* muscles of both eyes. Diagram V represents the left eye with its *external rectus*, *inferior rectus*, *inferior oblique*, and

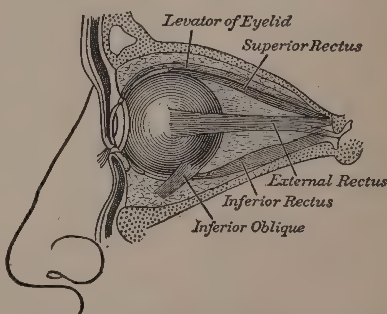
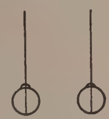
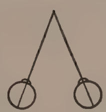


Diagram V. External lateral view of the muscles of the left eye.

superior rectus. The contractions of these twelve muscles are so adjusted and coördinated to one another that only certain movements are physiologically possible.

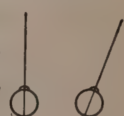
Two important classes of eye movements are distinguishable: those of *convergence* and those of *direction.* When the gaze is fixed upon some object at a great distance, for example, on the horizon, the lines of sight are parallel, thus:  To attend to nearer objects, the lines of sight must converge, thus:  This is accomplished by the two internal recti muscles chiefly. When the lines of sight are directed from an object near by to one farther away, the amount of convergence is decreased chiefly through the action of the external recti muscles. The entire set of twelve muscles is concerned in the steady fixation of any object, no matter what its distance may be. Apart from movements of convergence, the eyes may sweep together over the field of vision from right to left and in the opposite direction, or they may move up and down, and thus direct the lines of sight upon any point within the field of vision.

These movements of the eyes are under the control of the will, although they are generally accomplished without volition. The results of this experiment have shown that an object can be given continuous attention, for a time at least, despite the tendency of attractive visual stimuli to initiate, in a reflex way, the movements of the eyes necessary to gain for them exclusive possession of the vantage ground of the fovea centralis. The physiological adjustment of voluntary visual attention has appeared so significant to the human being that he has applied the expression "to direct attention" (which strictly means to direct the lines of sight of the eyes) by way of analogy, even to inner states of attention where no such adjustment of direction takes place. It is possible, with the eyes directed upon a finger, to give attention to another finger off to the side of the field of vision, without moving the eyes toward it. A "movement"

of visual attention is then accomplished without any movement of the eyes. Of course, attention does not strictly "move" in such cases. The feeling of movement connected with such inner direction of attention is due perhaps to slight movements of the eyes, which are checked before they have the chance to proceed very far, and also to other bodily movements normally associated with states of maximum attention. The brow may contract into a frown, the breathing, even the heart action and the flow of the blood may be somewhat affected.

In giving attention to mental images connected with vision, actual movements of the eyes take place. Thus in trying to hold in mind the picture of sheep jumping over a fence, some strain from the eyes may be noticed, and even coördinated movements, as the imaginary sheep leap the fence one by one. The turning of the head and eyes toward an object near at hand and about which one may be thinking has already been mentioned. It is particularly difficult, also, to avoid moving the eyes toward an object that is seen, off to the side of the field of vision, out of the corner of one's eye. The coördination of the eye muscles seems to be "touch and go" with certain visual perceptions and memories. But despite this readiness of the eye muscles to follow the mental cue, it is not possible for volition to bring about movements other than those for which the mechanism of the eye muscles is adapted. The lines of sight cannot be converged by unequal amounts, as, for example,

nor yet can one eye be moved independently of the other into such a position as this:



The adjustment of attention is due in part to the inherited automatic mechanism, which is at the disposal of consciousness and will for the execution of such movements as are in accord with its physiological nature. This automatic mechanism is also adapted to respond without volition, and perhaps even without consciousness, to stimuli acting upon the retina. It is, therefore,

extremely difficult to distinguish in any particular case voluntary from involuntary but conscious movements, and these from movements of the type exemplified by the pupillary reflex. It is possible, however, to distinguish different degrees of complexity in the muscular coördinations involved in the physiological adjustment of attention. At any one moment of attention to visual perceptions, four types of muscular coördinations will be represented. These are: (1) volitional coördinations; (2) automatic coördinations with consciousness; (3) automatic coördinations without consciousness, *i.e.*, complex physiological coördinations; (4) simple physiological coördinations, *i.e.*, reflexes. The muscles that take part in this coördinate adjustment are: (1) the iris, which regulates the number of rays permitted to act upon the retina; (2) the ciliary muscle, which accommodates the lens to the distance of an object and thereby accomplishes the same result as the photographer when he adjusts the ground glass of the camera to obtain clear definition; (3) the six muscles of each eye-globe, which cause the lines of sight of the two eyes to be directed simultaneously upon the same external object. A complete explanation of the production of voluntary, automatic, and reflex movements is the task of physiological psychology. The purpose of an analytical psychology, in this connection, is restricted to the ascertainment of the various factors that give mental contents the degree of vividness that distinguishes the state of attention. Although the stimuli themselves and the physiological mechanism are important contributory factors, the will and the constitution of the individual mind play the chief part in determining what each person shall make of his physical organism and of that common environment which supplies us all with the same raw materials of sensation. For this reason, we have considered the influence of certain individual mental characteristics embraced under the name of apperception, before proceeding to treat of the association and combination of mental

contents and of their relation to the process of sensation and to the physical stimuli.

Vision is chosen to illustrate the physiological adjustment of attention, because the muscular coördinations of the eyes are of great variety and complexity, and attention to perceptions through the sense of sight is intimately connected with the development of attention in general. Attention to perceptions received through the sense of hearing requires a similar adjustment of the two muscles of the mechanical parts of the ear, the *stapedius* and *tensor tympani* (see page 168). The muscular adjustment necessary for attention to perceptions received through the sense of smell is shown in the sniffing up of the odoriferous air; for attention to perceptions through the sense of taste, in the crushing of a tastable substance against the roof of the mouth and in the movement of the tongue to spread a liquid over the sensitive regions of the mouth cavity; for attention to perceptions of touch, in the movement of the more sensitive portions of the body, for example, the hands, and particularly the finger tips, over the surface of an external object.

CHAPTER III

ASSOCIATION

Experiment XIII. **The perception of an object is modified by associated perceptions from adjacent objects.**

A. *Size.*

1. Compare the circle a, Chart 8, surrounded by the smaller circles with the circle a' surrounded by the larger circles. Which appears to be the larger circle, a or a'? They are both of the same diameter.

2. Which appears to be the larger angle, b or b', Chart 8? They are exactly alike.

3. Does c or c' appear to be the larger section of the straight lines on Chart 8? They are of equal length.

B. *Color.*

1. Examine the charts numbered 9 to 14. Each chart comprises a colored sheet, upon which is placed a gray strip, and over both a sheet of transparent paper. Compare the color and shade of the gray strips on the red, green, yellow, blue, white, and black sheets respectively, when covered with the transparent paper. Observe that the tinge of color is complementary to the color of the background. This tinge is noticeable even when the transparent paper is removed, so that it may be difficult to convince yourself that the six gray strips are identical in tint and shade.

2. Arrange two lights of equal brightness, for example, two candles or two lamps, so that they will cast upon a white surface two similar shadows of a pencil interposed in an upright position. Place sheets of colored glass one after another before one of the lights, and compare the two shadows in each case. How is the shadow of the colored light affected?

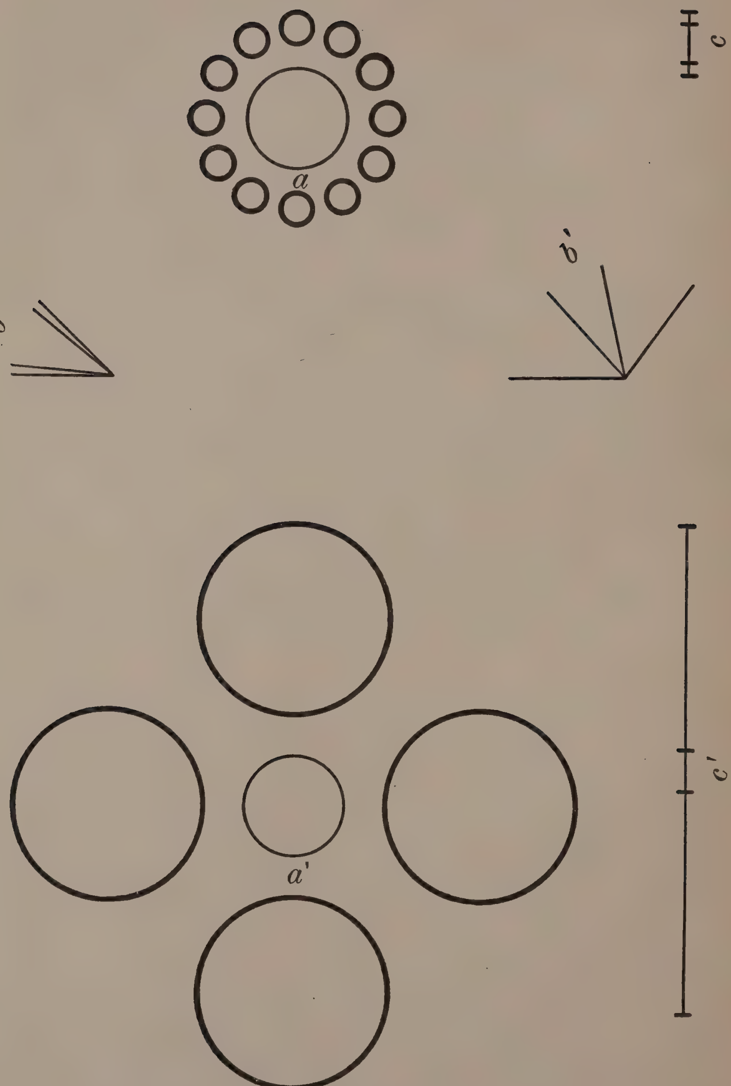


CHART 8

CHARTS 9—14

It would appear from these experiments that a perception of size or color, received from any object or part of an object, will depend in part upon other perceptions received at the same time from adjacent objects or adjacent parts of the same object. We may generalize from this fact and maintain that every sensation or perception will be modified, in some degree, by the sensations and perceptions *associated* with it. It has been suggested that the tinting of the gray strip or shadow in the color complementary to the background may be due to purely physiological processes in the retina. Although physiological processes doubtless contribute to the production of this illusion, the mental *association* of the perceptions themselves would appear sufficient to produce the result. A green background, for example, arouses an apperceptional expectancy for green in all parts of the visual field, in consequence of which a gray strip placed in the center of the green area is perceived as more removed from green than it really is. The color displacement of the gray strip is therefore in the direction of red, which is the contrasting complementary color sensation. This explanation is similar to that offered for the illusion of weight in Experiment VI, B.

EXPERIMENT XIV. **The extension of associated perceptions over the invisible portion of the field of external objects.**

A. *The blind spot of the retina.*

1. Fixate the cross on Chart 15 with the right eye, keeping the left eye closed and holding the chart close to the eye and in such position that the square, the triangle, and the large disc lie in a horizontal line to the right of the cross. Without moving the eye, you will be able to see the three figures. Move the chart slowly straight out from the eye. At a distance of about seven inches the square will suddenly disappear. If it should come suddenly back again, this will be due to the fact that the eye has been moved

rapidly toward it. In this case, bring the eye immediately back to the cross and hold the chart for some time in such position that the square cannot be seen at all, although the triangle and disc are clearly visible. Move the card slowly still farther out from the eye and you will find that at a distance of about eleven inches the square reappears and the triangle disappears. Move to a distance of sixteen inches and the large disc will have disappeared, although the other two figures will be plainly seen. Move the chart a few inches farther away and all the figures will be again visible.

2. Invert the chart so that the cross is in a horizontal line to the right of the figures. Close the right eye and look steadily at the cross with the left eye. Proceeding as directed above, cause the square, triangle, and disc to disappear successively.

When the eye fixates the cross, the image of the cross falls upon the fovea centralis. (See Diagram II.) If the chart is held close to the eye, the images of the square, triangle, and disc fall upon the lateral portions of the retina beyond the place of entrance of the optic nerve. The greater the distance of the chart from the eye, the nearer to the fovea will the three retinal images be situated. At certain distances ascertainable, as in this experiment, the image of each figure will fall entirely within the area from which the fibres of the optic nerve and the blood vessels supplying the inner structures of the eye are distributed over the inner surface of the retina. The result of this experiment shows that the fibres of the optic nerve are not directly sensitive to light, in consequence of which there is a *blind spot* of considerable area in each eye. In the right eye (see Diagram II) the blind spot is to the left of the fovea centralis, as is shown by the fact that objects to the right of the point fixated disappear.

The diagram on page 48 represents the appearance of the retina of the left eye as viewed through the pupil. The elliptical white spot represents the fovea centralis and macula lutea; to the left of this is seen the blind spot, from the center of

CHART 15

which radiate the arteries and veins, avoiding the fovea centralis. The fibres of the optic nerve are distributed in like manner. These are too fine to be represented in the diagram.

With both eyes open, an external object cannot be made to disappear under normal conditions, because the anatomical conformation of the two retinae is such that an object cannot cast both images at one time upon the blind spots of the two eyes. This may be demonstrated by employing a screen to cut off the light rays passing from the object to one of the two eyes.

DIAGRAM VI. A view of the retina of the left eye through the pupil.

3. Hold Chart 15 in such position that the word, the circle, and the tree are in the same horizontal line. Fixate the circle with one eye at a time. Move the chart toward the face or away from it until you find the place at which the tree disappears with the left eye closed and the word "tree" disappears with the right eye closed. Be careful that the chart is not moved after this alternate disappearance is obtained. Hold a narrow screen, such as a visiting card, directly between the root of the nose and the cross, so as to cut off the right eye's image of the word and the left eye's image of the tree. With both eyes open and directed upon the cross, the tree and word should now disappear from view; the image of the tree falls upon the blind spot of the right eye and is screened from the left, while the image of the word falls on the blind spot of the left eye and is screened from the right.

Some difficulty may be experienced in getting the proper position of the head, chart, and screen, and in holding the eyes fixed upon the cross. Any displacement from the proper position will throw one or both images off the blind spot and thereby bring the objects clearly into view. A man or even a larger

object may be made to disappear by screening one eye and seeking with the other the proper point in space to be fixated in order that the image of the man shall fall upon the blind spot. As the area of the blind spot is only from one-twelfth to one-fifteenth of an inch in diameter, the man must be far enough away to cause the retinal image to be small enough to fall within the area of the blind spot. The head of a man will fall entirely within this area at a distance of about six feet, and the whole body at a proportionately greater distance.

B. *The filling-out of the blind spot.*

1. In the preceding experiments, when the objects disappeared as they fell within the blind spot, what seemed to take their place?

2. Fixate the cross on Chart 16 and hold the chart so that the uncolored portions of the red and green strips disappear. Do you see the red and green strips continued over the area not colored?

3. Fixate the circle on Chart 16 and move the chart until the central area where the red and green squares are mutilated falls within the area of the blind spot. Do the squares now appear intact and to meet at a common point?

4. Cause the black disc between the interrupted circles on Chart 17 to disappear by fixating either one of the crosses, as may be convenient. Do you see the lines continued so as to make complete circles? Or do they appear as actually represented?

In the last experiment, the blind spot may be filled out by some persons with the white background of the paper, because the circles apparently are not distinctive enough to be continued as definite perceptions over the gap in sensation. Other persons will fill out the area with the associated perceptions of the circles.

5. In what way is the central area of the checkerboard on Chart 17 filled out, when this falls upon the blind spot?

As the optic nerve itself is not sensitive to light rays, an object, or the part of an object, from which the light rays fall upon the blind spot, might just as well be behind the head, so far as its effect upon vision is concerned. This void is filled by the mind with the associated perceptions from adjacent objects that stimulate the parts of the retina surrounding the blind spot. The *field of visual perception* is therefore continuous, although the *field of retinal excitation* is interrupted and the *field of external objects* includes a portion from which no perceptions are actually obtained. The *field of vision* is, in general, the aggregate of what can be and is seen at a single moment. In the study of vision, it is sometimes necessary to distinguish the *mental* or *psychical* field from the *retinal* or *physiological* field on the one hand, and from the *external* or *physical* field on the other, for as is here shown the three fields do not always correspond.

EXPERIMENT XV. **The field of vision.**

A. *The field of monocular vision.* Let the subject close the left eye and, standing erect before the blackboard, with the head about eight inches from the board, fixate with the open eye some mark made with white chalk upon the board at the height of the eyes. Let the experimenter first hold a piece of chalk in position near the mark upon the board. While the subject continues to hold his eye fixed upon the mark, let the experimenter move the chalk horizontally, close to the surface of the blackboard, first to the right and then to the left, asking the subject in each case to announce as soon as the chalk disappears from view. Mark the points on the board at which the chalk seems to disappear. The distance of these points from the point of fixation will vary proportionately with the distance of the eye from the surface of the board. Toward the nose, it will be found that the chalk disappears suddenly. In the opposite direction, the subject may report that the chalk does not disappear at all.

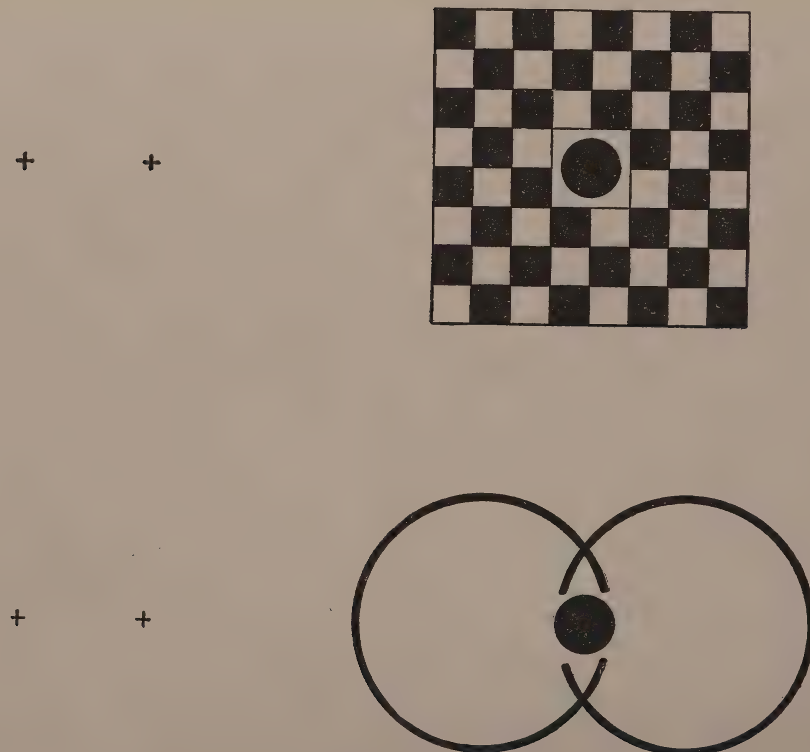


CHART 17

The *field of monocular vision* will be found to be limited in the horizontal line internally by the nose, while externally it is limited only by the sensitivity of the retina to stimuli acting from a distance.

Begin again with the chalk near the point of fixation and move it up and down in the vertical line, marking upon the board in a similar manner the points where the chalk disappears. The field of vision will be found to be limited in both directions.

Connect all these points by a continuous line. This will be a rough outline of the external field of vision. The subject may find the limits of his own field of vision by fixating a point marked upon a sheet of paper placed on a table or against the wall.

B. *The field of binocular vision.* Without changing the position of head and eyes, outline the field of vision of the left eye.

The accompanying diagram shows the right and left fields of vision, as determined for a subject in accordance with the

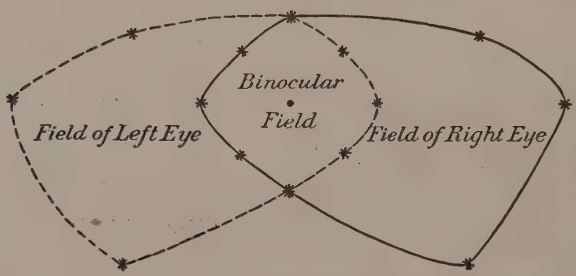


DIAGRAM VII. The outlines of the monocular and binocular fields of vision.

instructions of this experiment. The middle overlapping portion of the two fields is the *field of binocular vision.* Its outline is an irregular ellipse. The farther the point fixated is from the eyes, the larger will be the area enclosed by the lines representing the limits of the field of vision.

C. *The central area of distinct vision.*

1. Cut from a newspaper or other print a few clearly printed letters. Paste or otherwise fasten them to the end of a straw or pencil. Let the subject, with both eyes open, fixate a point on the blackboard or on a sheet of paper laid upon a table. Move a letter toward the point of fixation along vertical and horizontal lines, from the right, left, above, and below, beginning at a position where the letter cannot be seen. Require the subject to announce as soon as possible the letter seen. When he can correctly name the letter, mark the place upon the blackboard or paper. The line connecting the four points thus determined will enclose a central area of distinct vision, which corresponds roughly to the retinal area of the fovea centralis.

2. Fixate with both eyes any letter on this printed page, or a letter of the series on Chart 18, taking great care not to move the eyes. How many letters above and below, to the right and left of the letter fixated, can you see? How many letters beyond this area of distinct vision can you see dimly without being able to distinguish the particular letter? How far from the point of fixation can you distinguish print?

The *central area of distinct vision* contains all those objects to which attention can be given without movement of the eyes. But attention cannot be given at one time to each and every object within this area. They are perceived with distinctness only by a successive direction, or movement, of attention to one object after another. When a letter to the right of the point fixated is clearly distinguished, a letter to the left becomes indistinguishable. As will appear from the results of the next experiment, only a small number of the objects within the area of distinct vision can be vividly and discretely perceived through a single act of attention. Physiologically, the area of distinct vision is the area of vision with the fovea centralis, and may be called the area of foveal or central vision. Psychologically, it is the area over which attention can be successively distributed

without movement of the eyes. It may therefore be called the *field of visual attention with the eyes fixed.*

D. *The field of attention with the moving eyes.* Having determined the central area of the binocular field, as above, move the eyes successively to a position as far as convenient vertically up and down and horizontally to the right and the left. Determine for each position, as directed in C, the point at which a letter can be named, and connect the four points with a line as before.

The enclosed area is the field of visual perception with attentive eye movements. The eyes are moved over this field so rapidly, and for the most part so unconsciously, that all objects within the field are perceived distinctly and apparently simultaneously. It is more extensive than the binocular field of distinct vision with the eyes fixed in position, and is distinguished from the latter as the *habitual or normal field of visual attention.* The movements of the eyes are often accompanied by movements of the head. These are as unconsciously and almost as rapidly executed as the eye movements; they also serve to extend the limits of the field of visual attention.

EXPERIMENT XVI. **The number of discrete perceptions associated in a single act of attention, and the combination of the associated component parts of a single perception.**

A. *Simultaneous association.*

1. Cut from a sheet of paper or thin cardboard a rectangular slit $\frac{1}{8}$ inch wide and $2\frac{3}{4}$ inches long. Let the experimenter place this sheet over the letters of *a*, Chart 18, so as to expose only the fifteen letters in a single horizontal line. Place the chart before a subject with the exposed letters in easy position for reading. Let the subject read aloud the letters thus exposed. Move the sheet so that a new line of letters is exposed. Do not let the subject see

a

1.	d	p	b	m	s	n	l	v	w	t	f	z	h	r	g
2.	m	d	b	v	g	n	r	y	l	s	x	z	j	p	k
3.	q	w	r	t	y	p	s	d	f	g	h	j	l	m	v
4.	z	x	c	v	b	n	m	l	h	f	k	s	j	p	y
5.	t	f	y	l	g	m	w	d	s	x	b	v	c	r	q
6.	w	d	m	t	z	s	l	g	b	n	h	r	p	f	v
7.	d	m	t	z	s	l	g	b	n	v	f	w	h	r	p
8.	r	q	p	w	s	g	n	d	m	c	l	k	x	z	y
9.	n	g	p	q	d	r	v	t	m	x	z	q	l	s	w
10.	l	d	g	b	v	n	f	w	r	h	t	m	z	p	s
11.	b	w	m	s	p	z	y	r	t	d	g	v	n	f	l
12.	h	p	g	m	f	n	s	w	r	y	z	x	b	c	j
13.	j	y	p	k	l	b	m	s	d	n	f	w	z	x	q
14.	y	t	p	r	w	q	z	s	x	h	d	c	b	j	k
15.	k	h	p	l	j	y	t	m	r	w	n	q	b	s	z
16.	c	l	f	g	w	s	q	p	n	b	m	x	z	t	r
17.	g	n	t	w	s	q	d	x	z	b	k	m	p	t	n
18.	f	r	n	l	w	s	y	p	k	h	x	q	y	v	c
19.	w	l	r	h	m	s	x	p	c	g	b	v	z	y	q
20.	x	n	z	b	s	m	w	p	q	y	c	f	g	w	l

b

1.	cat	ran	mat	dog	hat	cow	got	boy
2.	met	tar	not	tun	tag	but	sat	got
3.	tot	wet	the	see	can	met	run	not
4.	run	bun	tan	bet	pin	bit	cur	low
5.	fin	pat	tow	rot	sir	mar	pot	par
6.	car	lap	nor	top	rap	pan	war	ton
7.	tub	vow	pit	ban	nap	pew	jot	man
8.	sap	box	day	tap	cap	bar	cog	pig
9.	hog	lit	cob	hop	sip	jog	jar	gab
10.	raw	den	raw	son	lax	cop	ban	wan
11.	bur	gag	gun	sup	keg	fat	rip	dim
12.	jab	oil	ear	try	cud	you	too	hum
13.	and	ewe	fob	doe	ant	ate	cat	age
14.	err	rue	ell	fur	fib	fun	gas	dub
15.	mar	are	gig	bib	nip	did	lag	law
16.	age	tan	caw	din	lie	pad	sin	maw
17.	wen	ail	eel	art	ell	bud	tog	hub
18.	nun	dab	hun	jag	log	yak	fed	yew
19.	egg	tea	tie	sag	tar	lit	yes	kit
20.	sol	you	nag	put	red	sew	sky	nay

CHART 18

these letters, using a piece of cardboard held just above the letters to screen them from his gaze. Direct the subject to prepare to read, as quickly as possible, the letters that will be exposed to view when the screening card is removed. Remove the card for a moment only, calling out "now" as a signal to the subject when the card is about to be removed. Require the subject to write down in order all the letters seen. Make in all ten trials, using a different line of letters on each trial. Be careful to keep the time of exposure as constant as possible. Record the number correctly seen at each trial and get the average number for the ten trials.

2. Repeat this procedure with the short words of *b*, Chart 18. Record the average number of short words and the average number of letters that can be seen as components of words.

3. Repeat with Chart 19, *a*, recording as before the average number of words and letters.

4. Repeat with Chart 19, *b*, recording the average number of words and letters that can be seen as components of sentences.

5. Collate (that is, put together in a single table) the average results of 1, 2, 3, and 4. Is it any more difficult to see a single word than it is to see a single letter?

All of the objects that are contained within the external field of vision, and hence are able to act upon the sense organ, do not produce perceptions of equal definiteness and discreteness. Those objects which act upon the lateral portions of the retina can produce but vague and indefinite mental contents. Of these, psychology can say little more than that they exist and may, through a subsequent accession of vividness and distinctness, acquire a proportionately important place in consciousness. Nor yet do all the objects that may be contained within the area of distinct vision give rise to separate and discrete perceptions. If the object of perception is a building, the several bricks of the building cannot give rise each to a distinctive perception. These are stimuli to the retina, the several mental results of which are very closely *associated or combined* in the single and unitary perception of the building.

a

1. horse cart when plenty back
2. rest where expose handy human
3. expense desk drain empty late
4. perhaps society soul wild will
5. whisper whistle cover pair wool
6. paper walk street mire roller
7. room full curtain book paste
8. listless longer words boards
9. city town country weather walk
10. cross church choir angel write
11. soil slight whittle lisp pail
12. willing rain trail paint ordain
13. sailor whoop sunk boat wave
14. stealth first ball wasp honey
15. daring teller money kink wagon
16. count yawl race toil sloop
17. master union sister sling wall
18. salad parlor onion bear bald
19. foot cherry peacock pile tame
20. never palm desert camel sheep

b

1. All the world 's a stage.
2. Never mind what he says.
3. Here a little, there a little.
4. Hope to see you soon again.
5. A bird in the hand is worth two in the bush.
6. Large bodies are said to move slowly.
7. The spacious firmament on high.
8. Birds are singing in every tree.
9. We watched the stately ships pass by.
10. What is so rare as a day in June?
11. Honey is sweet to the taste.
12. The unfathomable depths of the sea.
13. This is only a passing shower.
14. He fell through pride of power.
15. A gleam of sunlight through the wood.
16. A strong purpose possessed his mind.
17. He was swimming with an easy stroke.
18. Do not let us quarrel any more.
19. The moon and stars are overhead.
20. Parallel lines can never meet.

Chart 19

A word is a group of objects, *i.e.*, letters. At an early period of individual development, a perception of the whole word may not have been so readily formed as the perception of a component letter of the word. Through repeated experience, the discrete perceptions of letters combine with an ever-increasing degree of intimacy. Education makes possible an immediate synthesis of the mental results of the individual letters so as to form the combined but unitary perception of a word, and even the synthesis of words to form the unitary perception of a phrase or sentence.

The following table collates a student's results of the present experiment.

Averages of ten trials.	Single letters.	Short words.	Long words.	Sentences.
Av. No. of Letters . .	3.	9.6	17.5	18.1
" " " Words . .		3.2	3.5	4.9

The time of exposure having been constant, the table shows that it takes as long to see three separate letters as it does to see 3.2 short words, 3.5 longer words, or 4.9 words connected in a sentence. Words are perceived with about the same facility as are the single letters of which the words are composed. The table also shows that the short words thus simultaneously perceived comprise on the average 9.6 letters, the long words 17.5 letters, and the sentences 18.1 letters. It would misstate these results to maintain that 9.6 letters, for example, can be perceived when they are the component parts of short words. When fifteen letters are simultaneously exposed to view, as in the experiment with Chart 18, *a*, three of these letters give rise each to a separate and distinct perception. The 9.6 letters are not perceived in like manner; they are the objects or stimuli which act together to give perceptions of 3.2 words. The

perception of a word requires one act of attention ; the perception of a letter of the word requires another and different act of attention. In the first chapter, we saw that a perception is formed by the synthesis of a part which represents the results of former experience and a part which is the result of the stimulation of a sense organ. We now find that a perception is also a synthesis of a number of mental contents which are associated together through the simultaneous action of several stimuli. In this synthesis of the associated component parts of a perception, we recognize the same constructive activity of the mind that we then designated apperception.

The number of discrete perceptions that can be associated in a single moment of attention and yet be separately distinguished is five, three or four certainly, six or seven doubtfully. This fact is ascertained by reducing the duration of the stimuli (the time of exposure) to a fraction of a second. The purpose of this is to prevent a movement of the eyes, and also the movement of attention, over the several objects of the field of vision. The number of discrete perceptions will then be limited to as many as can be associated in a single act or grasp of attention. It is shown that about five objects can be perceived as readily as one. These objects may be simple or complex ; for example, five letters or five words. As there is an ascertainable limit to the number of discrete perceptions associated in a single act of attention, so also is there a limit to the synthesis of mental contents associated in a single unitary perception. Most minds can grasp as a unit of perception the group of words comprising a phrase or short sentence. It is reported, though not yet proven, that some, with equal readiness, can apprehend groups of sentences as units of perception and thought.

B. *Successive association.*

1. Let the experimenter tap on the table with a pencil or any hard object at a constant rate of two or three taps to the second. Vary

the number of taps given in a single series from three to ten, and require the subjects, without counting, to write down the number of taps heard in each series. Make five experiments with each series. From the results of all the subjects, determine the average number of taps that can be held in mind as discrete perceptions.

2. Let the subjects be prepared to receive words at dictation and let the experimenter dictate, from some simple prose selection, connected groups of words, requiring the subjects to write the words from memory after they have been dictated. Increase the number of words dictated at one time, until all, or nearly all, of the subjects find it impossible to write down correctly all the words received. Find in this way the average number of words that can be received at dictation. Observe that the number will vary with the relatedness of the words to one another, with the unity of the thought conveyed by the words, and with the interest in the matter dictated.

A single act of attention may embrace several discrete perceptions that follow one another in sequence and which are then said to be *successively associated.* Five simple sounds, words, or other objects, represent approximately the maximum limit of this successive association of discrete perceptions.

The component parts of a single perception may be *successively* as well as *simultaneously associated.* It is a familiar experience that we immediately grasp as a unit of perception a number of words closely associated in succession. In hearing a passage read we do not get the sense word by word. We apprehend at once entire phrases and even sentences. Every perception is a synthesis, accomplished through apperception, of simultaneously and successively associated component parts. The experiments of this chapter have illustrated, hitherto, the association of uncombined and discrete mental contents. We shall now proceed to consider the simultaneous and successive association of mental contents comprised in a single perception.

Experiment XVII. **A complete perception of an object involves a movement of the eyes and attention over the component parts of the object.**

A. Observe the three designs of Chart 20. Notice the incessant movement of the eyes over the lines of the designs. Do the eyes in attentive observation move from right to left or, in the reverse direction, from left to right?

It will be noticed by most subjects that the eyes follow with some attention the lines of the design from the left toward the right, returning from right to left with a hasty and inattentive movement. These designs are perceived by an attentive movement of the eyes, generally from left to right, over the prominent lines. This attentive *exploitation* of the design gives rise to a succession of associated partial perceptions which are combined in the complete perception of the object.

B. 1. Observe the design *a* on Chart 21. Do you notice a tendency of the eyes to move from a point at the lower portion of the figure outward and upward over the curved elements of the design?

2. What are the movements of the eyes and attention over *b* and *e* of Chart 21?

3. Why does the square *c* appear taller than *d*? Observe carefully the part of each square which first attracts attention.

A prominent point or line of an object first receives attention; from this the subsequent movements of the eyes and of attention will take their origin. Thus in Figs. *a*, *b*, and *e*, Chart 21, the initial point of regard is near the base of the design, and attentive observation passes upward. The middle horizontal line of Fig. *d*, Chart 21, receives and holds attention, whereas some will fixate the base line and others the upper line of Fig. *c*. The point or line receiving initial attention is called

the *center of orientation*, *i.e.*, the part with reference to which the figure is "sized up" or given distinctive character. In an attentive examination of *d*, for example, the eyes move along the figure in the direction of the middle horizontal line; the square is thus divided into two equal rectangles, an upper and a lower. The subsequent movements of exploitation are then forced to pass over a series of parallel vertical lines. As each vertical line tends to hold the eyes fixed upon it, there results a momentary, even though unnoticeable, arrest of attention, whereby the time required to exploit horizontally is increased and the distance moved over by the eyes appears greater. With *c*, on the other hand, the eyes do not move horizontally at all. The figure is exploited in the vertical direction, the eyes passing up and down along the vertical lines with unimpeded movements. Figure *d* is therefore *oriented* from the middle line as two rectangles, and *exploited* by horizontal movements of attention, whereas *c* is oriented as a single square and exploited vertically. This difference in the exploitation of the two equal squares gives rise to a difference in the associated components of the perceptions and thereby causes *c* to appear taller than *d*.

The associated partial perceptions which are synthetized to form the complete perception are obtained from successive movements of the eyes and attention over the parts of the object. The manner of this distribution of attention will determine the character and number of the component mental contents. To distinguish two different phases of this distribution of attention, the one from the other, and also to emphasize the fact that the perception of an object is not a single stable view but a succession of views obtained from a movement of active attention, we have employed the term "orientation" to designate the attention to the dominant part or characteristic of the object, and the term "exploitation" to designate the attention given successively to the other parts. The latter are always apprehended in relation to the dominant part.

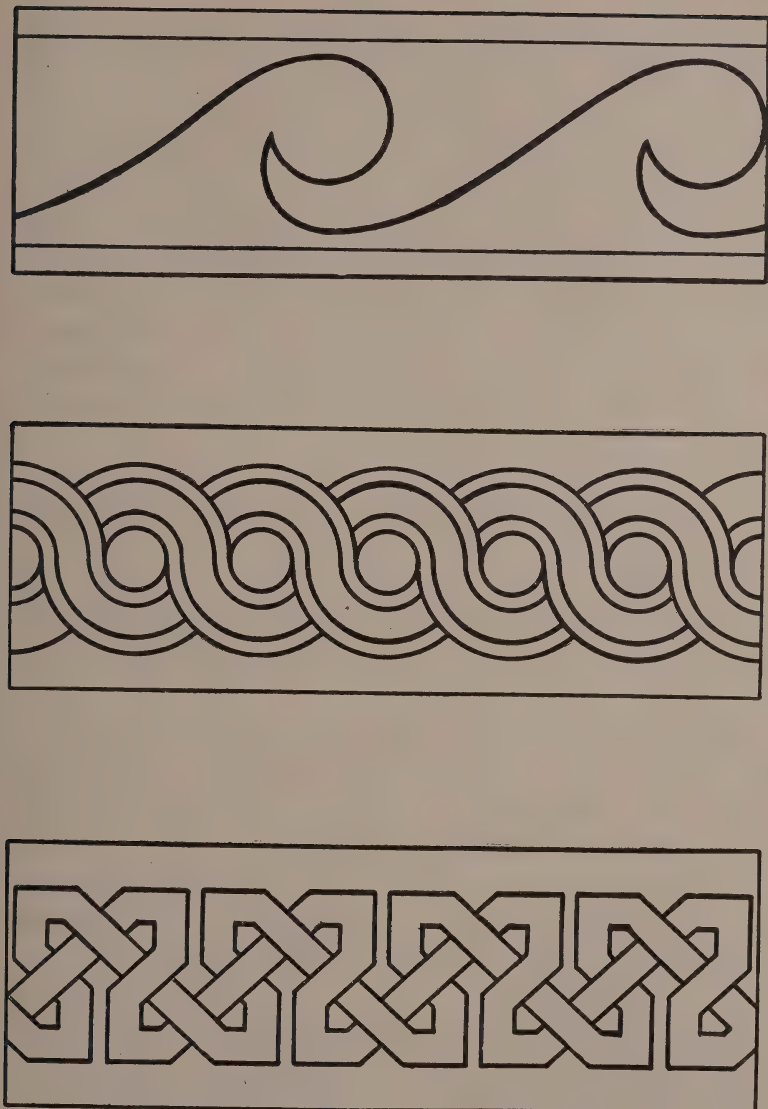


CHART 20

Exploitation may not always appear necessary to form a complete perception. An outline of a square, for example, may be perceived as a complete square, even when illuminated by the electric spark, which endures for too short a time to permit of a movement of the eyes over the lines of the figure. There is certainly, in this instance, no exploitation of the parts of the external object. There is, however, an exploitation of its visual image. A very small part of a square, even the word "square," may suffice to call up in mind the complete visual image of the square. This image is then contributed chiefly by the reproductive process of memory and not by sensation. It is exploited as the external object would have been had it acted for a longer time upon the eyes.

Experiment XVIII. **Habitual or normal modes of orientation and exploitation.**

A. Compare the square *a* of Chart 22 with the diamond *c* on the same chart. Do they not look like entirely different figures? Are they not both squares? Which is the more pleasing figure?

The different appearance which these two figures present is due to their different orientation and exploitation. The square is habitually oriented from the base line with movements of the eyes upward, as may be thus represented: 

The dotted line indicates the line of orientation and the arrows the direction of exploitation. The diamond may be oriented from the lower point, with upward exploitation, thus: 

Frequently, however, the center of the diamond is taken as a point of orientation from which exploitation radiates by successive movements outward, as may be indicated by the arrows, thus: 

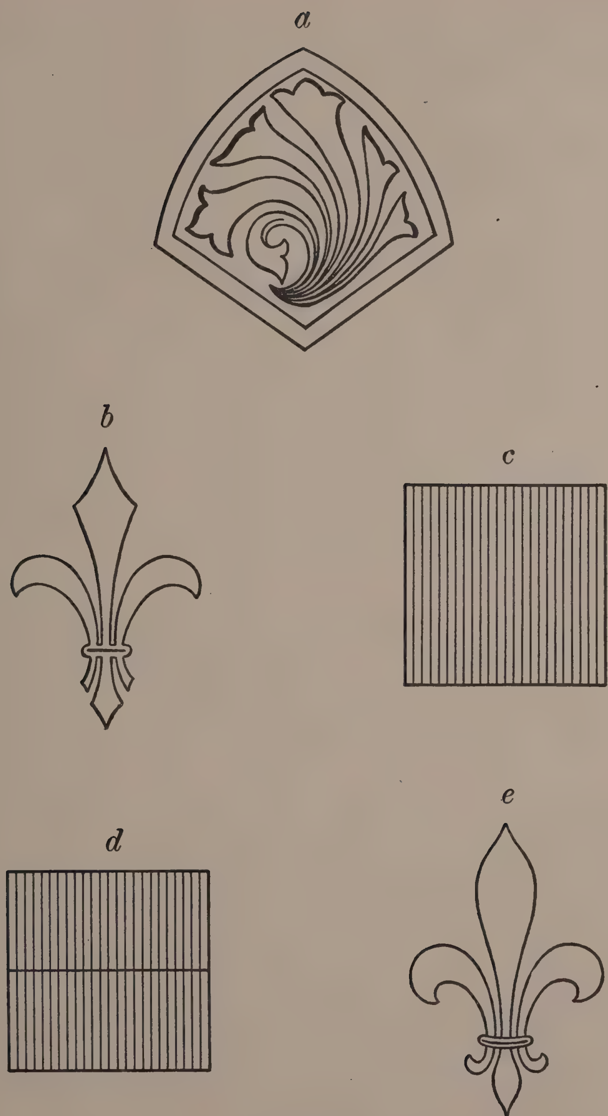


CHART 21

Some persons seem to divide the diamond into two symmetrical halves by an imaginary line of orientation, thus: 

What may be considered secondary movements of exploitation follow the outlines of the figures, moving usually in the direction of the hands of a clock, thus: 

Inasmuch as the directions of the component lines of the two figures are entirely unlike, the movements of attentive regard differ radically in the exploitation of the two figures. Different muscular coördinations and even different muscles are involved in the two cases, with the result that the two perceptions are composed of very dissimilar component sensations and perceptions. The diamond will be instantly perceived as a square tilted up on a corner, if it is exploited in the same way as is the square, *i.e.*, by a single movement of the eyes obliquely upward from a base line, thus: 

B. Examine *d*, *e*, *f* of Chart 22. Although these are geometrically identical figures, does not *d* appear totally different from *e* and *f*? Indicate the orientation and exploitation of these figures by dotted lines. Which position of the figure do you prefer, as in *e* or in *f*? Does not *e* look somewhat "back-handed"?

The figure, *f*, is exploited by an oblique line upward and to the right, whereas *e* is exploited by an oblique line upward and to the left. Movements of the eyes toward the right are more easily performed than those toward the left. The greater aesthetic value of *f* over *e* would seem to depend upon this relatively greater ease of eye movements to the right. If you imagine the figures *e* and *f* to be suspended from their upper lines, the upper line of each becomes the line of orientation from which the exploitation is obliquely downward. To such as can force themselves to regard the figures in this manner, *f* often appears less pleasing and more awkward when compared with *e*.

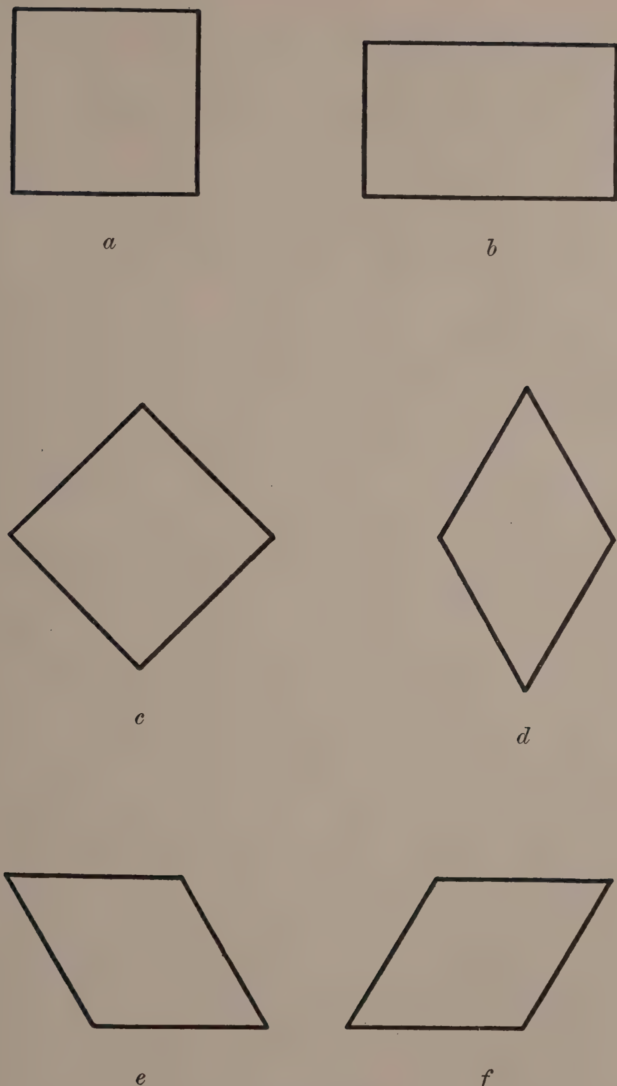


CHART 22

This is due to the fact that the exploiting movement of *f* is then to the left, while that of *e* is to the right. It would appear from these experiments that an exploiting movement is more habitual or natural upward than downward, and to the right than to the left.

C. How are the figures, *a*, *b*, *c*, *d*, and *e*, of Chart 23, oriented and exploited?

The orienting line of the circle is its own circumference, and along it, also, exploitation takes place, rotating in the direction of the hands of a clock, as may be represented thus: 

This can be designated *rotatory* exploitation. There is also a tendency to move the eyes inward from the circumference toward the center, a *convergent* exploitation, indicated in the preceding diagram by the arrows pointing toward the center of the circle. A contrary *divergent* exploitation is also manifested moving outward from the center of the circle, thus: 

In *d* and *e*, the center of the circle is clearly the center of orientation, from which the eyes are moved outward to the circumference along the radii of the circle in what is a *divergent radiating exploitation.* Careful observation will show also a movement of the eyes and attention over the successive sectors of the figure and around the circumference. In *c*, the horizontal line, as the line of orientation, divides the circle into two equal parts. Exploitation of this figure is consequently accomplished by equivalent movements above and below the horizontal line. The figure is therefore *vertically symmetrical.* In *b*, the vertical diameter gives rise to equivalent exploitation to the right and left; the figure is therefore *horizontally symmetrical.* Figure *d* is variously symmetrical (of equal measure); the eye movements along the radii from the center outward are equal and similar, and in passing over the sectors by a rotatory exploitation, the

eyes meet equal parts successively. The figure therefore presents both a fourfold *radiating* and a fourfold *rotatory symmetry*. Figure *e* similarly possesses an eightfold radiating and rotatory symmetry. The undivided circle, *a*, is often regarded as a perfectly symmetrical figure, because every point of the circle is at an equal distance from its center. This view is not justified, because the exploitation of the circle by a continuous movement about its circumference does not present any equivalent movements whatever, nor any repetition of similar parts. The circle is therefore not a symmetrical figure, but a type of the perfectly unitary figure. The figures, *b*, *c*, *d*, and *e*, are divided into varying numbers of similar parts. These figures are both unitary and symmetrical.

D. *Symmetry and proportion in the vertical and the horizontal line.*

1. Examine the eight vertical lines, divided into equal and unequal parts by cross-bars, on Chart 23. Does any one of these eight figures present a more pleasing appearance than another? Which is least pleasing in appearance? Do you prefer the lines *A*, *B*, and *C*, in which the shorter portion is above the longer portion, to the lines *F*, *G*, and *H*, in which the shorter portion is below the longer?

The cross-bar of *E* divides the line into two equal parts. These parts, however, appear unequal, because of the normal overestimation of the upper part of a vertical line in comparison with the lower part. The cross-bar of *D* is so placed as to appear to most eyes to divide the line into two equal or symmetrical portions. In the three lines, *A*, *B*, and *C*, the cross-bars are at different distances above the middle point of the lines. In *F*, *G*, and *H*, the cross-bars are below. At first sight, it seems impossible, if not absurd, to say that one line is more pleasing in appearance than another. Many persons, however, express a slight preference for a line with the cross-bar above the center, as, for example, the line *C*.

2. Invert the chart. Do you now prefer the cross-bar above or below the center of the line? Do you think of the lines as suspended from the upper end, or as standing upon the lower end? When you observe a line attentively, do you move the eyes from the bottom up or from the top down?

When the eyes are moved with attention from the bottom up, the lines will appear to be standing. If your selection is restricted to lines divided into unequal parts, a line with the cross-bar above the center will generally have a slight preference. When the eyes are moved from the top down, the lines will appear to be suspended. A line with the cross-bar below the center will then be preferred. In moving the eyes over unequal parts of a line, it is more pleasing to pass from a longer to a shorter section than from a shorter to a longer. It would be absurd to assert that any one of the lines on the chart is beautiful or has great aesthetic value. Nevertheless, even a very slight preference for one mode of dividing a line may grow into a decided opinion of the beauty or ugliness of an object, if that object forces upon our attention, along with its other characteristics, an arrangement of unequal and equal parts. We learn from a study of the relative aesthetic effect of these simple lines, that the natural exploitation of vertical distances is upward, unless something in the figure or some association causes the eyes and the attention to begin the movement of exploitation at the upper end.

3. Turn the chart so that the lines are horizontal. The line *E* will now appear to be equally divided. There is little or no overestimation of the part of a line to the right relative to the part to the left. Do you find that the symmetrical division is much more pleasing when the line is horizontal than when it is vertical?

4. Compare *C* and *E* in the horizontal position, and *C* and *D* in the vertical position. Is the symmetrically divided line certainly the most pleasing of all, when the lines are in the horizontal

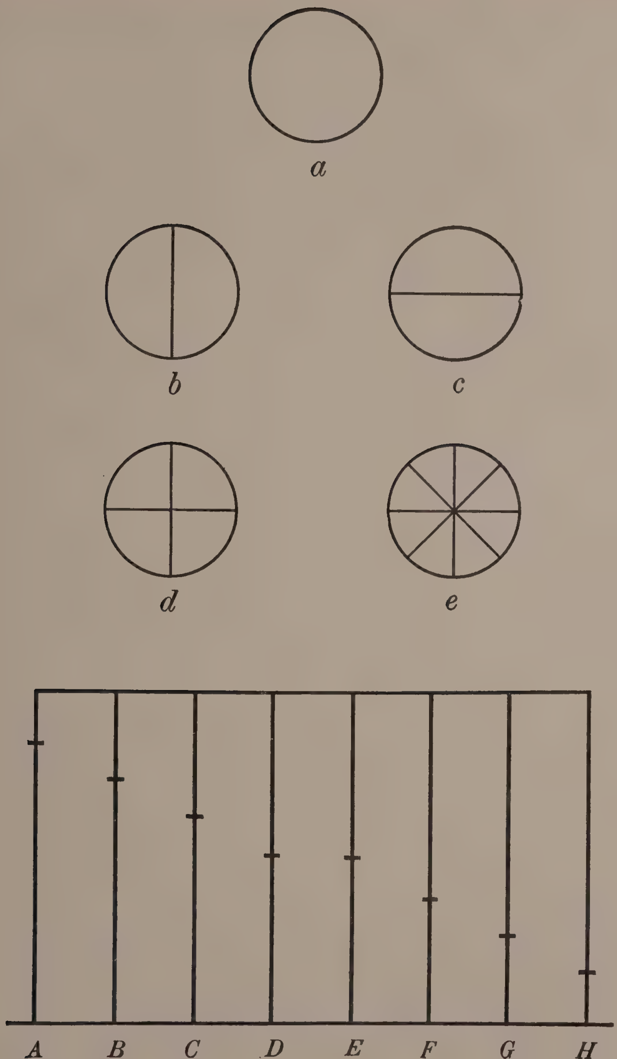


CHART 23

position? Are you in doubt as to the relative merits of the equal and unequal divisions in the vertical position, perhaps inclining to prefer the unequal division?

To exploit a horizontal line, the eyes seize first upon a middle point or portion of the line and then seek to make equal movements to the right and left. This is in accordance with the anatomical relations of the eyes and their twelve muscles, and also with the normal habits of vision developed by the environment. When attention is fixed on objects straight before us, or on the ground at some distance, we are in position to make movements of the eyes equally to the right and to the left. Movements downward, however, are limited in extent and unimportant compared with movements upward, as, for example, the raising of the eyes from the ground to view a tree or building.

In consequence of these conditions, *dual symmetry* has greater aesthetic value in the horizontal than in the vertical line. Horizontal dual symmetry is commonly known as *bilateral symmetry.* It is found in almost every work of art, and indeed in many objects of nature, for example, the human body.

5. Compare *A*, *B*, and *C* in the vertical position. Which of the three unequal divisions do you prefer?

Most persons prefer *C*, or some approximate division of the line.

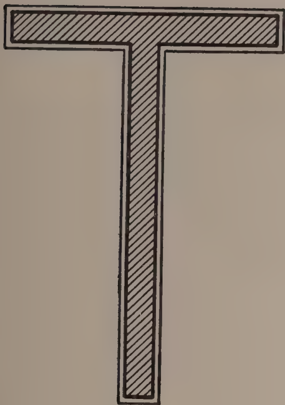
When the cross-bar stands at the middle point of a line, the line is divided into two equal parts and the ratio of the lengths of the two parts can be expressed as 1 : 1, no matter what the actual length of the line may be. Suppose the cross-bar to be moved gradually toward the upper extremity. As the upper part becomes smaller and the lower part larger, the ratio between the upper and lower parts will change at certain intervals from that of 1 : 1 to one of 1 : 1½, 1 : 2, 1 : 3, etc. At one end of the

series we shall have a pleasing equality of parts, and at the other a very displeasing inequality of parts. Is there a pleasing inequality of parts? Experimentation and the practice of the arts have answered this question in the affirmative. When the ratio between the parts is about that of 3:5, or 1:1.66+, the line will produce a pleasing effect. This ratio is nearly that of *C* and *F* on the chart. Some will prefer a line in which there is a greater difference between the two parts, and others will choose one in which there is a less amount of difference. The majority of persons, however, will select a division of the line in which the ratio of the two parts is approximately that of 3:5. A pleasing inequality of the parts of a line, the ratio of 3:5 or any other preferred ratio, we may call *proportion*, to distinguish it from the pleasing equality of parts, which has been designated *symmetry*.

Suppose that we try to divide the line in such manner that the ratio between the shorter and longer parts of the line is the same as the ratio between the longer part of the line and the whole line. If the length of the shorter section is x and the length of the longer section is y, then this division requires that $x:y=y:x+y$. This division of the line is known as the *golden section*. A line cannot be divided exactly in accordance with the requirements of the golden section. It can be shown by mathematical calculation that if the length of the shorter part is 1, the length of the longer part must be 1.618+, a quantity the exact value of which cannot be determined. In *C*, the ratio of the parts is 3:5, or 1:1.66+. The most pleasing "proportion" would seem to be an approximation to the golden section. It has been held that this "proportion" is pleasing because it gives to a figure an equality of ratios, *i.e.*, that of the shorter and longer parts on the one hand, and of the longer part and the whole line on the other. It was also maintained that a more cultivated aesthetic taste would prefer proportion to symmetry, because of the more

complicated equality presented by the golden section. It seems to be true that the development of taste leads to a preference of proportion to symmetry, especially in the vertical direction. But the cause of this is not the demand for an equality of ratios, but a demand merely for greater variety. Symmetrical figures are divided into parts monotonously alike; proportional figures have their parts unlike. The amount of unlikeness or variety that is pleasing will depend upon the general character of the object, and upon the individual's grade of intelligence and aesthetic taste. The ratio of "proportion" is not fixed as is that of symmetry. It is only as a very rough approximation that the ratio of 3 : 5 can be said to represent the most pleasing mean between a too great inequality or variety and a too great equality or sameness.

In comparing these different lines to determine which is the most pleasing proportion between the parts of a line, many will find it difficult to avoid associations with swords, daggers, telegraph poles, trees, and crosses. Indeed, some are inclined to think at first that it is these associations, and not the proportion, which are the chief source of the greater or less aesthetic value ascribed to the several figures. That the human mind manifests an aesthetic appreciation of proportion in the vertical line is shown in the historical development of the form of the cross of Christian art. The cross was originally T-shaped, or had the cross-bar very high up on the vertical (see *a* and *b*, Chart 24). In early forms of the cross (*b* is from the catacombs of S. Ponziano and dates from the fourth century or earlier), the cross-bar has a higher position than it occupies on the two crosses, *c* and *d*, of Chart 24, the former being a cross used for personal ornament and the latter an ecclesiastical cross of the fifteenth century. As the historic symbol was adapted for church and personal ornament, the cross-bar dropped down in the course of centuries to satisfy an aesthetic demand for proportion in the vertical line.



a

b

c

d

CHART 24

E. *Symmetry and proportion in complex figures.* Compare Figs. *a* and *b* on Chart 22, opposite page 66. Which do you prefer as a figure, the rectangle or the square?

Most persons prefer the rectangle to the square, though not a few find the square the more pleasing. The four sides of the square are of the same length, whereas the vertical magnitude of the rectangle is in the ratio of 3 : 5 with the horizontal. The square is therefore completely symmetrical, the rectangle being proportional, although not entirely without symmetry. The square is pleasing because of the equality of all its parts; the rectangle is more pleasing because it affords a greater variety of partial perceptions. Experiments in aesthetics as well as experience with the forms of art show that proportion between vertical and horizontal magnitudes is preferred to symmetry. This aesthetic demand determines to some extent the forms of books, envelopes, windows, picture frames, and many other objects of the useful and the fine arts.

We have learned from the results of the preceding experiments that the perception of an object is obtained by associating together many partial perceptions of the object. The manner in which these component parts are combined in the complete perception will depend in part upon the constructional elements of the object itself. But to a much greater degree will a particular combination be determined by universal or individual habits of distributing attention over the parts of the object. These habits of attention are, in the last analysis, habits of apperception. The movement of active attention, as appeared from the experiments of Chapter II, is the result of an acquired tendency to select the particular objects, or parts of an object, to be given vivid mental existence. A simple or complex work of art will produce the desired aesthetic effect only when some measure of conformity to these apperceptional habits is realized. If an object is to be perceived with aesthetic pleasure, all its

parts must be apprehended with distinctness and yet in combination; and this must be accomplished with readiness and ease. We do not mean by this that the object which we perceive most easily will give us the greatest amount of aesthetic pleasure. The cultivation of aesthetic taste is a training to perceive progressively more complex things with the maximum of ease. The development of apperception facilitates the combination of the component parts of complex perceptions. Insufficient training causes one person to view a thing of beauty with indifference, because he will see it as a simple thing or he will see only a part of it; another person will view it with distressing effort or even with mental confusion, because he has not acquired adequate facility in constructing the complete perception of a complex object. A few simple illustrations drawn from the visual arts will demonstrate this dependence of aesthetic perception upon the apperceptional habits manifested in the distribution of attention.

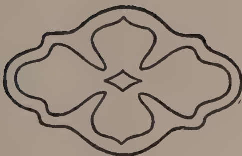
A movement of the eyes and attention upward is preferred to a like movement downward. The actual movement enforced by the construction of the designs, Figs. *a*, *b*, and *e*, on Chart 21, is upward. The designs appeal to the habitual mode of exploitation. If the chart is inverted, exploitation will be forced by the designs to follow a downward direction. The designs have a much more pleasing aesthetic effect if they are viewed as placed upon the chart than if inverted.

The aesthetic value of bilateral symmetry, which was shown to depend upon the natural mode of orienting and exploiting horizontal lines, is well established. The employment of proportion in the vertical direction, in preference to dual symmetry, was illustrated by the cross of Christian art. Figure *a* of Chart 25 possesses both horizontal and vertical symmetry, and between the horizontal and vertical elements there is the characteristic proportion to which attention was called in the simpler figure of the rectangle.

Decorative art occasionally employs designs that do not conform to the general tendencies of natural exploitation. These exceptions, on careful examination, often show that the decoration has suggested some unusual exploitation, which, for the time being, is substituted for the more natural one. Thus Fig. *b*, Chart 25, is a decorative hinge for a door. Its form as well as its position on the door will suggest movements of the eyes in the horizontal direction from left to right rather than the more usual exploitation from the center with equivalent movements to the right and left. In consequence of this suggested exploitation, it is not displeasing to find proportion in the horizontal and symmetry in the vertical direction.

It was also demonstrated that, in the exploitation of horizontal lines, a movement from left to right is preferred to one in the opposite direction. This is beautifully illustrated in Fig. *c* of Chart 25, which contains, in addition to the dual symmetry of the figures in the lower part of the design and to the right and left, a middle portion not bilaterally symmetrical. This central design possesses what may be called *running symmetry*, the same element being repeated five and a half times. Attention moves over this design from left to right more readily than from right to left.

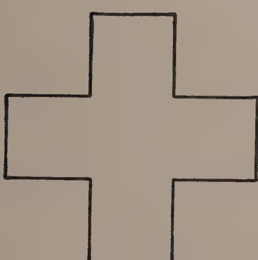
Radiating symmetry is frequently employed in decorative art. It is the basis of construction of the Greek cross, which in its simplest form is composed merely of four equal arms radiating at right angles from a center (Fig. *d*, Chart 25). A simple treatment of this variety of radiating symmetry is to be found in the cross from the church of St. Sophia (Fig. *e*, Chart 25). The radiating design (Fig. *a*, Chart 26) presents a more complicated treatment, each of the four members or elements being composed of three sub-elements having dual symmetry. Another example of Byzantine decoration (Fig. *b*, Chart 26) presents a different treatment of the same characteristic design. In this there are two groups of four symmetrical elements



a

b

c



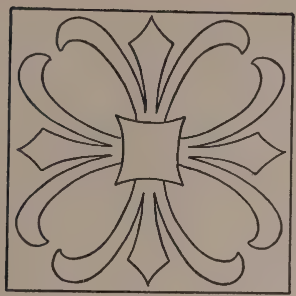
d

e

CHART 25

radiating from a common center, the four elements of the two groups alternating. The design from St. Mark's (Fig. *d* on the same chart) develops the two groups of four radiating elements from simple elements presenting both dual symmetry and proportion. A design of the Renaissance period (Fig. *c*, Chart 26) limits the number of radiating elements to two groups of three each, developed from component elements of complicated but generally symmetrical construction. Radiating designs which contain an even number of elements, four, six, eight, and so on, such as Figs. *a*, *b*, *d*, and *e* of Chart 26, always possess dual symmetry as well as radiating symmetry; but radial designs composed of an odd number of elements, for example, Fig. *c*, do not possess such dual symmetry.

The number of radiating elements may be indefinitely large. In Fig. *f* of Chart 26 there are fifteen elements, presenting a beautiful and complex variety of manifold radiating symmetry. The eyes exploit this design also with a circular movement. In doing so, they pass in succession over symmetrical parts of the design, giving rise to a manifold rotatory symmetry. The manner in which rotatory exploitation may be suggested by some very simple feature is shown in the representation of a part of a stained glass window from the Soissons cathedral. This design (Fig. *e*, Chart 26) possesses a fourfold radiating symmetry in two groups of four elements, but the four elements near the periphery draw attention from the center, and their form causes the eyes to move about the border of the design. Rotatory exploitation is very marked in the detail of a piece of French sculpture portrayed as Fig. *a* of Chart 27. Careful examination of the complicated design (Fig. *b* of Chart 27) will disclose illustrations of many different kinds of symmetry. The design seems to have what may be called "movement," because the most prominent part of the design is composed of the six complicated elements which continually attract the eyes to move over them, as though in a restless



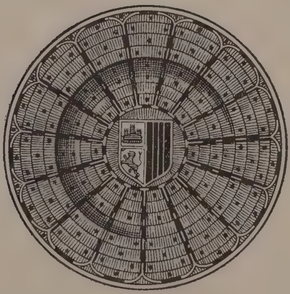
a

b

c

d

e



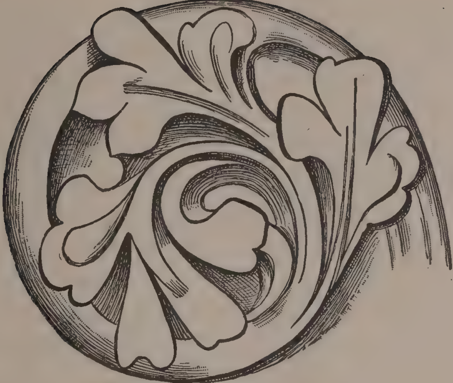
f

CHART 26

search for some point of fixation. The figure has a dominant rotatory symmetry. But it possesses also manifold radiating symmetry, because the eyes in moving outward from the center will pass over equivalent elements of design. It also possesses manifold dual symmetry, for if a straight line were drawn entirely across the figure through the center, similar elements would be found along this line at equal distances and in opposite directions from the center. If the larger elements of the design are studied to ascertain the forms of symmetry employed in their construction, it will be found that they all, despite their complicated character, fall within the classes and types which have been described above. The constructive elements of this design are developed in such a complicated manner, that the figure inspires but never gratifies the effort to apperceive a fixed relation of its parts.

It has been stated that proportion is more pleasing than symmetry because it possesses greater variety. It is also susceptible of more complex treatment. Designs combining proportion and symmetry are not so readily apperceived and in consequence appeal to a more highly developed aesthetic sense. In church edifices, the historical development of architecture is shown to be away from symmetrical forms of dominant horizontal lines to the more complex forms of proportion in dominant vertical lines. Thus the Greek temple employed the simplest kind of symmetry. The early Christian church, modified from the Roman temple, developed a more complicated treatment of symmetry, but still used dominant horizontal lines. The cathedral of Cologne, a magnificent example of Gothic art, is marked by dominant vertical lines of exploitation and a more pronounced use of proportion.

Pictorial art exemplifies the same general rules. In the celebrated painting by Raphael, the Sistine Madonna (Chart 28), the figure of the Virgin first attracts and holds attention. The picture being thus oriented along the central vertical line, the



a

b

CHART 27

position of the two figures to the right and left gives, in the horizontal direction, an evident bilateral symmetry. In the vertical direction, however, there is not the least suggestion of symmetry, but in its stead a noticeable proportion between the two kneeling figures and the standing Madonna. A conspicuous tendency appears in the course of the development of pictorial art to employ, even in the horizontal direction, the proportional relation in preference to symmetry.

In unsymmetrical paintings, the center of orientation is most frequently in parts to the left, and the movement of exploitation is from left to right. This characteristic exploitation is shown in one of the oldest works of art, the Wounded Lioness (Chart 29), which dates from the seventh century before the Christian era. The center of initial regard is undoubtedly the head of the lioness. The eyes view the figure by passing down the sloping body of the lioness in one of the most pleasing lines of movement in the visual field. The famous Aurora of Guido Reni (Chart 29), also, requires orientation in the left of the picture and exploitation toward the right. The chariot and the figures about it attract attention first, and from them the eyes move to the right and upward in a graceful curve. This curve is repeated, though not always in the same position, in a number of figures, particularly in the Cupid with the extended horn and in the figure nearest to the horses. The curved line extending from the foot and draped right leg to the head is practically the same as the dominant line of the painting. If the illustrations of any book are examined, they will be found more frequently to require movements of the eyes from left to right than in the opposite direction.

The exploiting movements of the eyes may be suggested by the figures of a painting. Thus the cherubs in the Sistine Madonna are gazing upward to the right. In looking at this picture, it is almost impossible to keep the eyes from following

CHART 28

Chart 29

the gaze of the cherubs. An object in that direction will be observed long before the hands and arms of the cherubs are seen. This picture may be examined by some persons for a considerable length of time before they take the slightest notice of the hands; this may be proved by removing the picture from view and asking for details as to the number and position of the hands represented. The larger figures of the picture also suggest lines of direction for the movement of attention. Thus the figure to the right is looking downward toward the cherubs, that toward the left is gazing up into the face of the Madonna, while the direct gaze of the Madonna draws attention to the middle portion of the picture. In this, as in many pictures, the unity of the scene is largely enhanced by the skillful arrangement of the lines of sight of the figures portrayed.

It is not possible to discuss at this time the aesthetic value of different curved lines. Neither psychology nor aesthetic criticism has reached a position of great certainty with regard to the more pleasing forms of such lines. Hogarth's serpentine line of beauty is constructed by tracing a spiral line of a single turn upon the surface of a cone from its apex to its base. The form of this curve will depend upon the relative dimensions of the height of the cone and the diameter of its base. Hogarth was not able to establish these proportions more definitely than to assert that the cone must be neither too tall nor too short. Nothing more definite can be maintained than that gradual curves are more pleasing than abrupt ones. In general, curved lines have greater aesthetic value than straight lines. A gradual curve upward to the right, the dominant curve of the Aurora, is perhaps the most pleasing line. It is also the line that best accords with the relative ease of natural and acquired movements of attention. Next in order is a curved line downward and to the right. Following this in ease of exploitation and in aesthetic value is a curved line upward and to the left. A

line downward and to the left satisfies least the requirements of apperception and aesthetic appreciation.

In this treatment of the elements of visual forms, only the simplest conditions of aesthetic perception have been considered. Other aesthetic demands will of necessity modify and may even completely antagonize those which have been here presented. It would be absurd to look for the employment and realization of these apperceptional motives in every work of art or nature that appeals to the sense of beauty. It is maintained, only, that these factors will be found along with others that contribute to the perceptions of such objects as awaken the responsive emotion of aesthetic appreciation.

Experiment XIX. **Visual illusions of space.**

A. *Linear dimensions and areas.*

1. Compare the apparent lengths of the horizontal lines on Chart 30. In which figures does the horizontal line appear longest? In which does it appear shortest?

These lines are all of the same length. The horizontal lines in those figures which cause attention to be directed inward from the ends of the line, are apparently contracted and shortened when compared with lines of the same length in figures that compel attention to move outward from the ends of the line.

2. Do the horizontal lines of the defective squares, *a* and *b*, on Chart 31, appear to be longer than the vertical lines?

These figures are exploited by a movement of attention over their constituent lines. The eyes and attention slip off the ends of the horizontal lines, and thereby extend the exploitation of the figures outward to the right and left respectively. The unrestricted and really greater movement to the right and

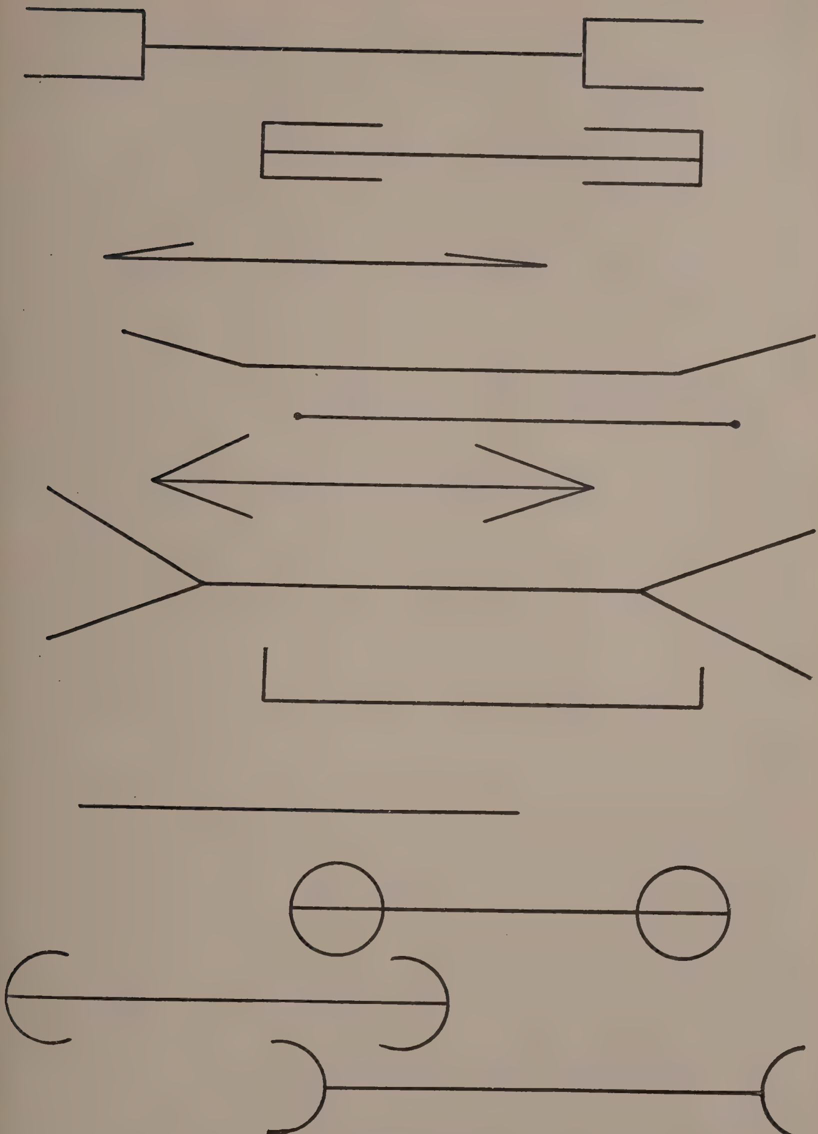


Chart 30

left increases the apparent length of the horizontal lines, when these are compared with the vertical lines. On close examination, the horizontal lines give oftentimes a fleeting impression of being not exactly parallel. At one end, they are held or pulled together by the concentration of attention on the vertical lines; at the other end, they are separated by the divergent movement of attention toward the extended area beyond the figures. It is even observed by some that the horizontals of *b* appear to be longer than those of *a*. The area toward which attention is directed is much larger in *b* than in *a*, owing to the position of the two figures on the chart.

Some subjects will not see the illusions just described. Some will report illusions even in the opposite direction. This holds true of nearly all the illusions considered in this section of the Manual. It is to be expected that different persons will view these figures in different ways. Although a figure may be so drawn as to force the attention of most subjects to the parts desired, some will, nevertheless, distribute attention in accordance with individual habits of apperception.

3. How do the three circles *a*, *b*, and *c* on Chart 31 compare in apparent size?

These circles are all of the same diameter, although *a* appears to be larger than *b*, and *b* larger than *c*. In comparing circle *c* with circle *a*, *c* is viewed as a part of the broad area vaguely defined by the diverging lines of the angle. On the other hand, *a* stands out in consciousness with distinctness, attention being drawn to its center by the lines converging to the apex of the angle. It was shown on page 68 that the circle is habitually exploited by movements around its circumference and inward toward the center. This will cause an apparent contraction of the circle when compared with figures that are exploited from the center outward. Circle *c* receives this natural exploitation;

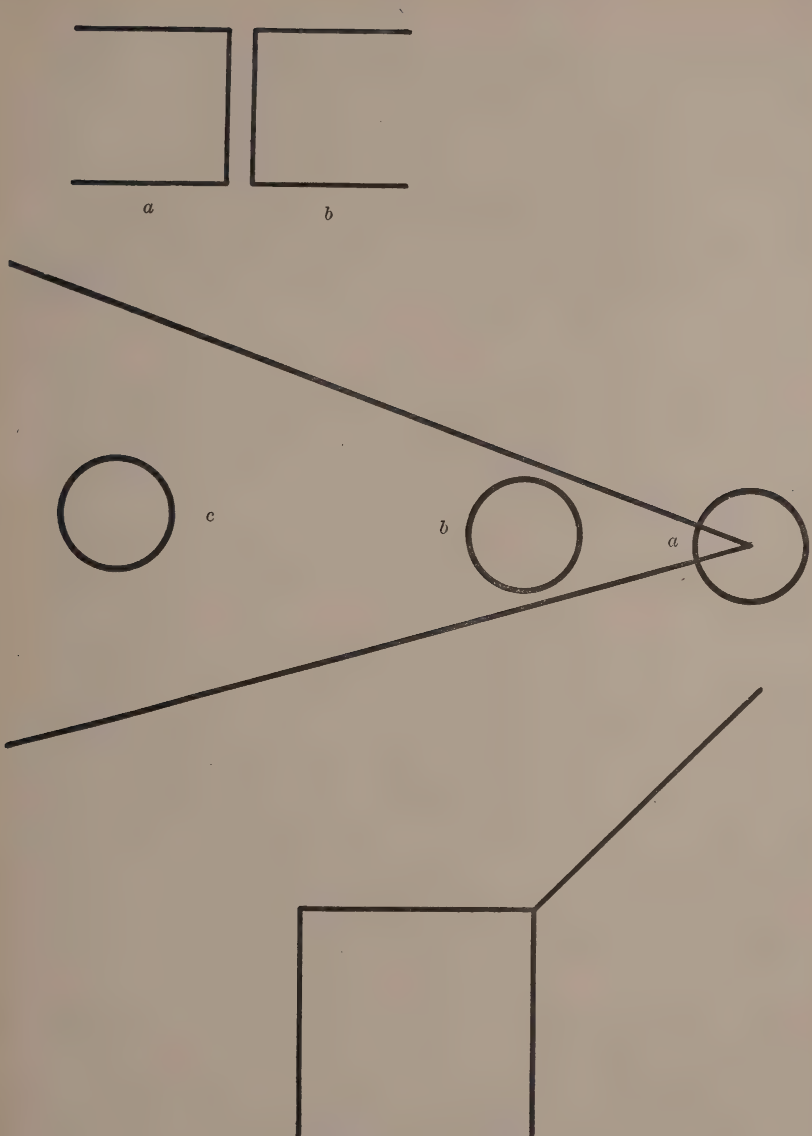


CHART 31

circle *a*, however, is exploited outward toward the circumference from its center, to which initial attention is forced by the apex of the angle. Circle *b* is probably exploited only around its circumference. Its area is associated with the small area enclosed within the converging lines of the angle. Contrast between the associated areas to which the two circles are respectively referred causes *b* to appear larger than *c*. Different modes of exploitation, however, cause *a* to appear larger than either *b* or *c*.

4. Take three small coins, — pennies, for example. Place two of them on the table just far enough apart to permit of passing the third coin between them, but adjust the two coins without trial with the third coin. Place the third coin between the other two. Did you leave sufficient space? When the middle coin is removed after being in line between the other two, does the space which it has just occupied appear to be more than sufficient to contain the coin?

The coin is bounded by a circular line. Areas with circular boundaries appear to be smaller than equally extensive areas having any other form of boundary. The convergent exploitation of a circular area will cause the two coins on the table to appear small in comparison with the area between them. The boundaries of the latter area are only partially defined by the outer convex lines of the coins; in consequence, this area is given more extensive and divergent exploitation, resulting in the apparent increase of its relative dimensions.

5. Compare the trapezoids *c* and *c'* on Chart 32. Which appears the larger? Why?

6. Which of the two equal lines appears to be the longer, — the upper horizontal line of *d* or the lower horizontal of *d'*? Why?

7. Which is the broader rectangle, *a* or *a'*, on Chart 32?

8. Compare the apparent size of Figs. *b* and *b'*, Chart 32.

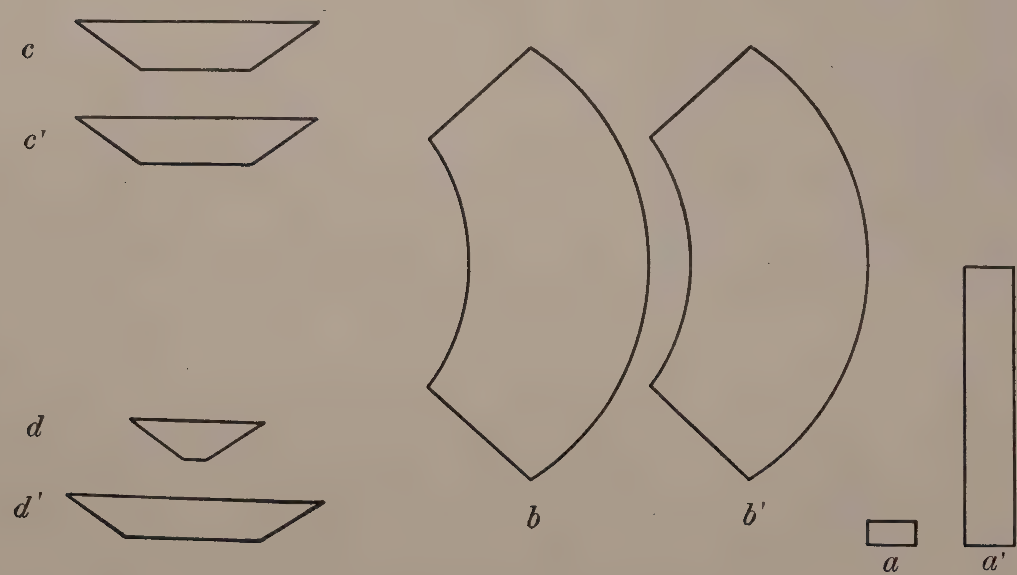


CHART 32

In all the foregoing figures, the effect of contrast is increased by movements of the eyes and attention, enforced by the lines of the figures.

B. *Filled and unfilled space.*

1. Compare the six equal linear magnitudes, represented in *a*, *b*, and *c* on Chart 33 by an empty stretch, a series of dots, a straight line, and a line with cross-bars.

The unfilled stretch appears to be the shortest, and the line with the cross-bars or the line of dots the longest. This overestimation of filled as compared with unfilled space is partly due to the relative difficulty and interruption of the eye movements of attentive exploitation. But the physiological processes of the retina also contribute to the illusion. A line of dots will cause a greater physiological excitation of the retina than an equal stretch of space limited by two dots as terminals. The effect of physiological processes upon perception will be considered in Chapter V. A similar illusion is found in space-perceptions received through the sense of touch (see page 154), under conditions that exclude movements as contributory factors.

2. Why does the filled right angle of Fig. *d*, Chart 33, appear larger than the unfilled angle?

C. *The overestimation of vertical compared with horizontal distance.* Observe the apparent lengths of the vertical and horizontal lines in *e* and *f*.

These lines are all of the same length. Eye movements in the vertical direction are performed with greater difficulty than in the horizontal direction. For this reason also a perfect square always appears taller than it is broad. (See Fig. *a* of Chart 22, opposite page 66.)

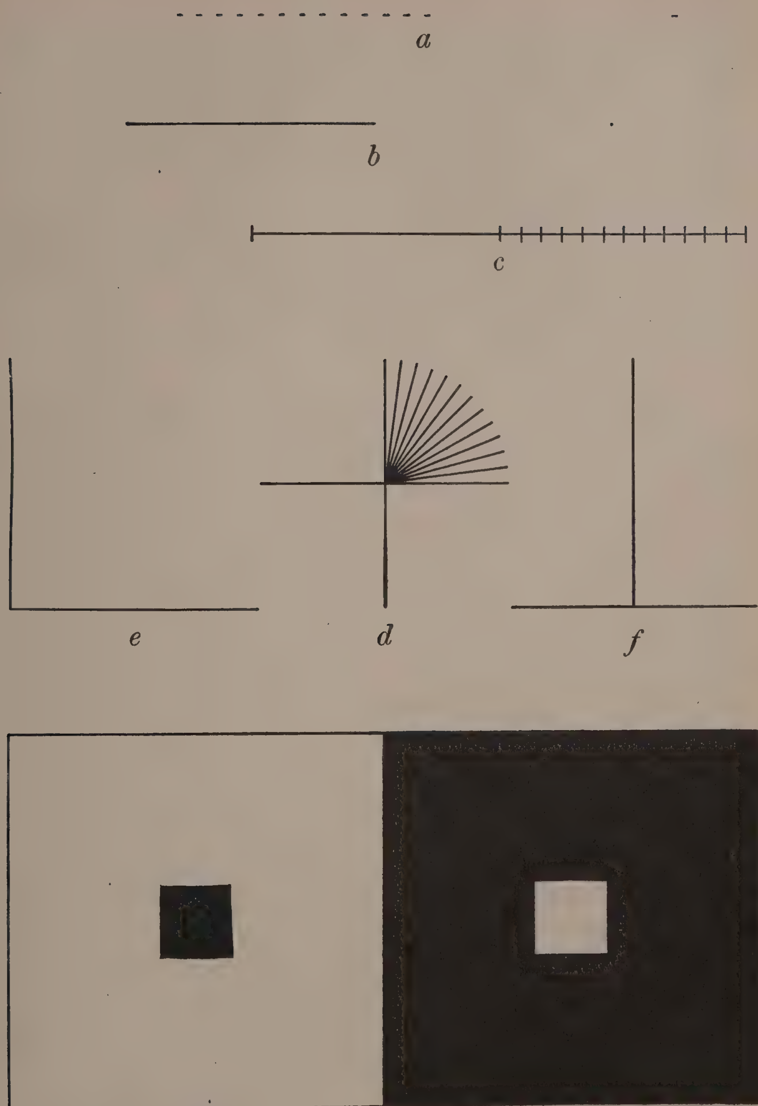


CHART 33

D. *The overestimation of the upper as compared with the lower part of a vertical line.* Draw a line of any length, say four inches; hold the line vertical before the eyes; without changing the position of the line with reference to the eyes, divide the line by a cross-bar into two apparently equal parts. Invert the line. Do the parts now appear equal?

This illusion is probably due to an increasing difficulty in the movement of the eyes as they pass upward from the point of initial regard at the base of the line.

E. *Distortion and displacement.*

1. Does the square on Chart 31, opposite page 88, appear to be drawn up obliquely in the direction of the line extending from its upper right-hand corner? Why?

2. Compare the two semicircles, a and a', on Chart 34. Why does a' appear to be a portion of a larger circle than a, and why does the distance between the free ends of the curved line appear to be greater than the diameter of a?

3. Observe in Figs. b and b' a similar but greater distortion of the equal arcs of similar circles.

4. Do the small disconnected arcs of the circles c and c' appear to be in what would be the continued line of the circumference of the circles? Why?

5. Are the three dashes of Fig. a on Chart 35 exactly in line with the lower lines of the two pairs of parallels?

6. When Chart 35 is held so that the lines of Fig. b are horizontal, the line to the left is clearly the continuation of the middle line of the three parallel lines. Turn the chart so that the three lines to the right are directed obliquely downward. Does the single line then appear to be the continuation of the upper line of the parallels? Turn the chart so that the three lines are directed obliquely upward. Of which of the three parallels is the single line the apparent continuation?

7. Which of the dots of Fig. c on Chart 35 seems to be in a straight line with the continuation of the oblique line? Lay the

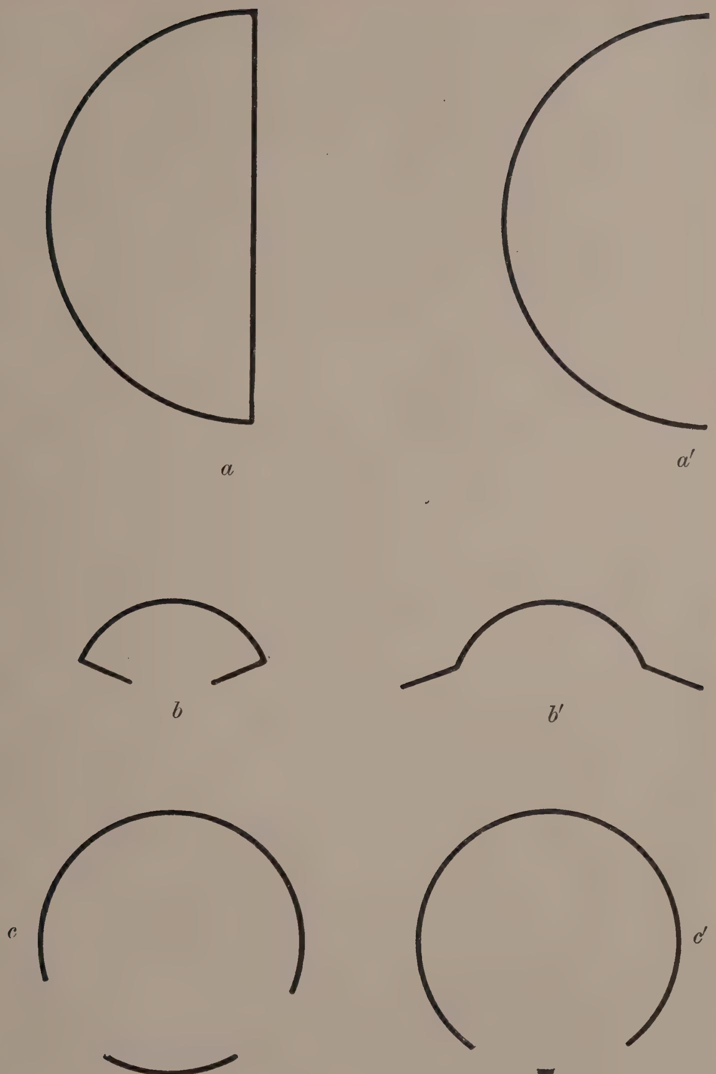


CHART 34

CHART 35

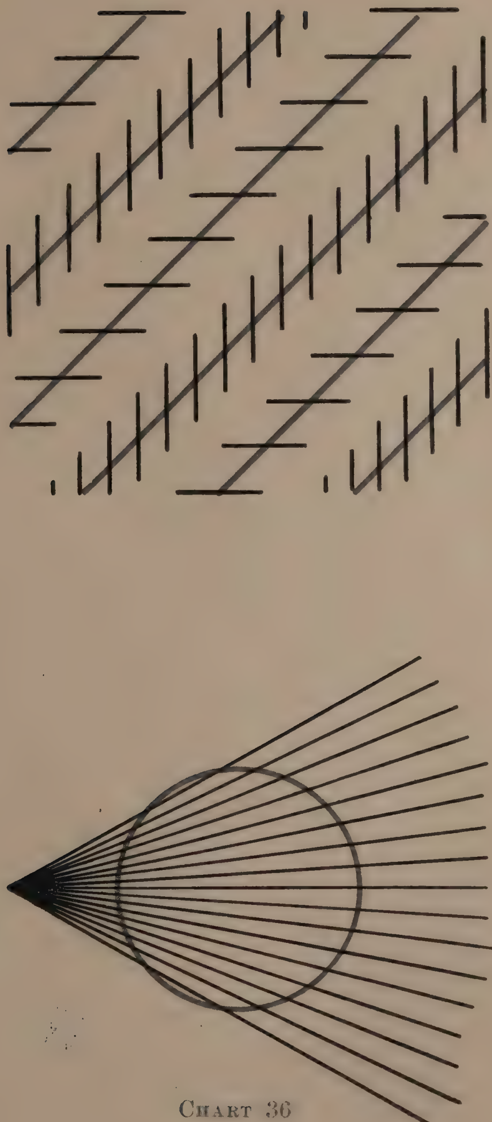


CHART 36

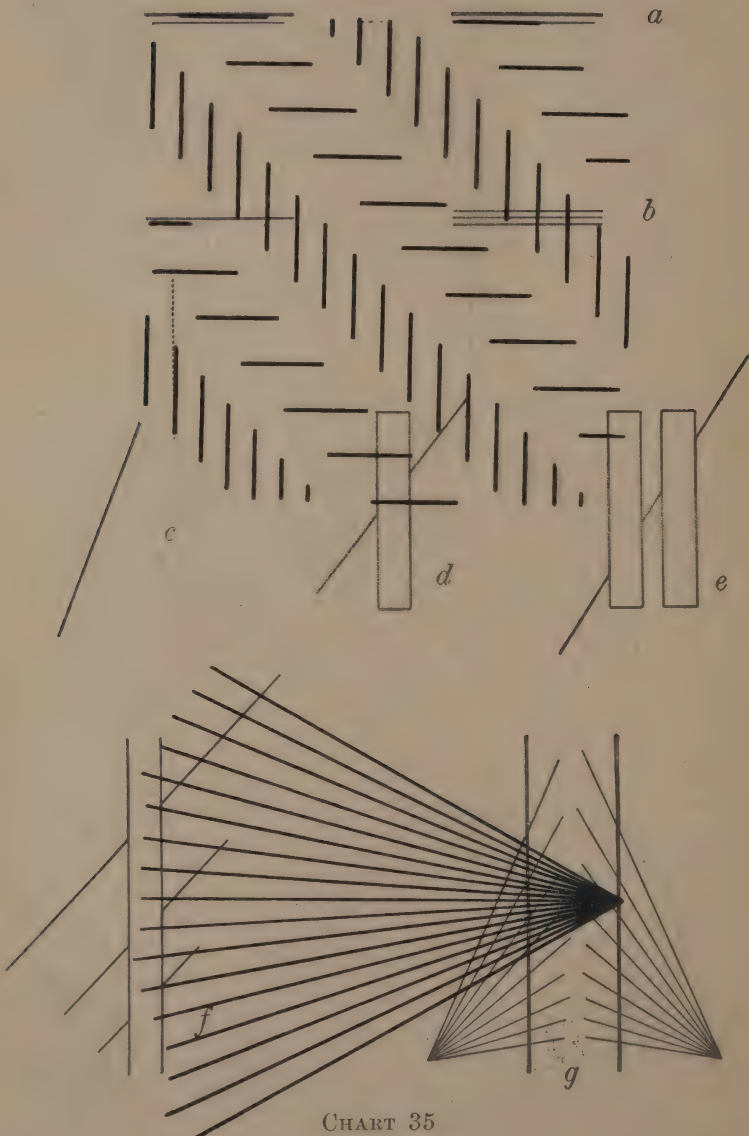


CHART 35

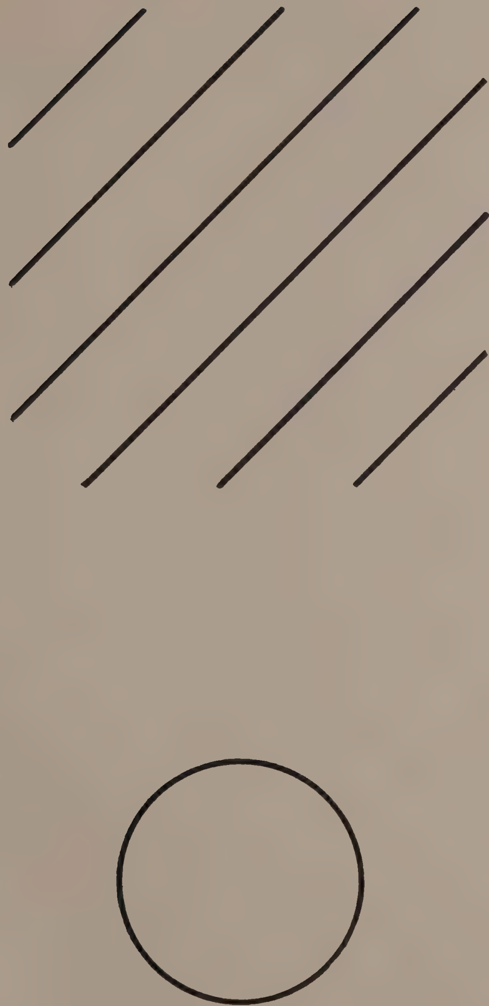


Chart 36

straight edge of a card to the oblique line and find where the oblique would actually cut the line of dots.

8. Do the two oblique lines of Fig. *d*, Chart 35, appear to be in the same straight line or does one oblique line appear to be higher than the apparent continuation of the other oblique line? Are the three oblique lines of Fig. *e* in the same straight line? Turn the chart so that the oblique lines of Figs. *d* and *e* are horizontal. Does the illusion disappear entirely or only in part? Does the illusion disappear when the broken lines are vertical? Observe the three pairs of oblique lines in Fig. *f*, Chart 35. Is the illusion greatest with the shortest lines?

9. What cause can you assign for the distortion of the two parallel vertical lines of Fig. *g*, Chart 35?

10. Why are the oblique parallel lines on Chart 36 no longer parallel, and why is the circle distorted, when these are viewed through the transparent sheet?

11. Observe the very marked distortion of the two parallel lines, on Chart 37, induced by the radiating lines, when the transparent sheet is superimposed.

It is impossible to offer a satisfactory explanation of all these illusions. Different psychologists will give not only different but oftentimes quite contradictory explanations of the same illusion. Very many different factors work, sometimes together, sometimes in opposition, to determine a given illusion. Some of these factors are the physiological processes of the retina, the relative difficulty and extent of the movements of the eyes, the association of the perception in question with perceptions from other objects in the field of vision, and the mode of orienting and exploiting the associated component parts of the object. These illusions are presented in this place in the Manual to give the student an opportunity of studying the diverse associations of partial perceptions, that result from different modes of distributing attention over the parts of the object. All the illusions are dependent in some way upon the direction of

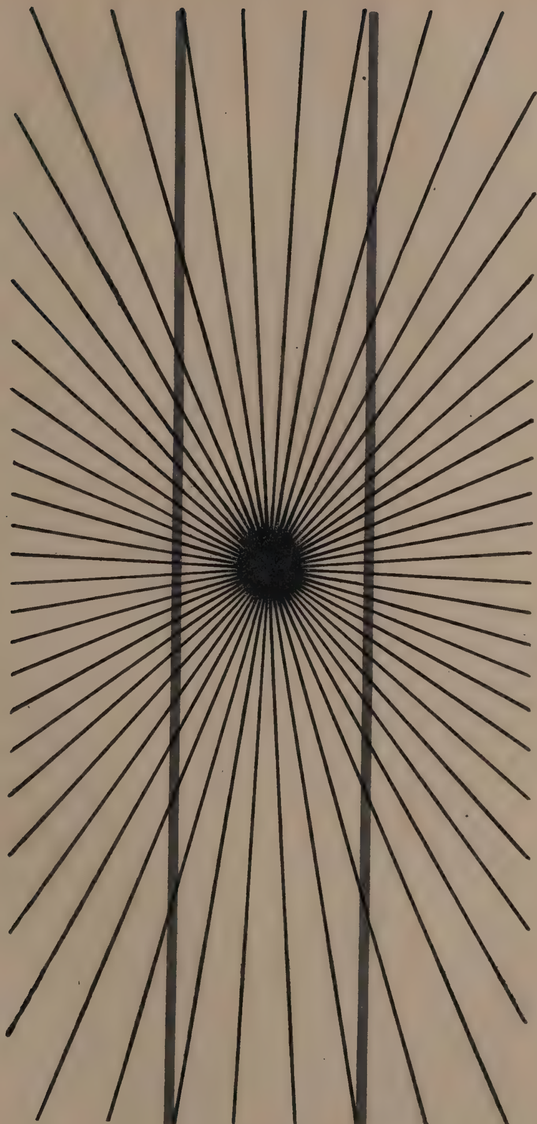
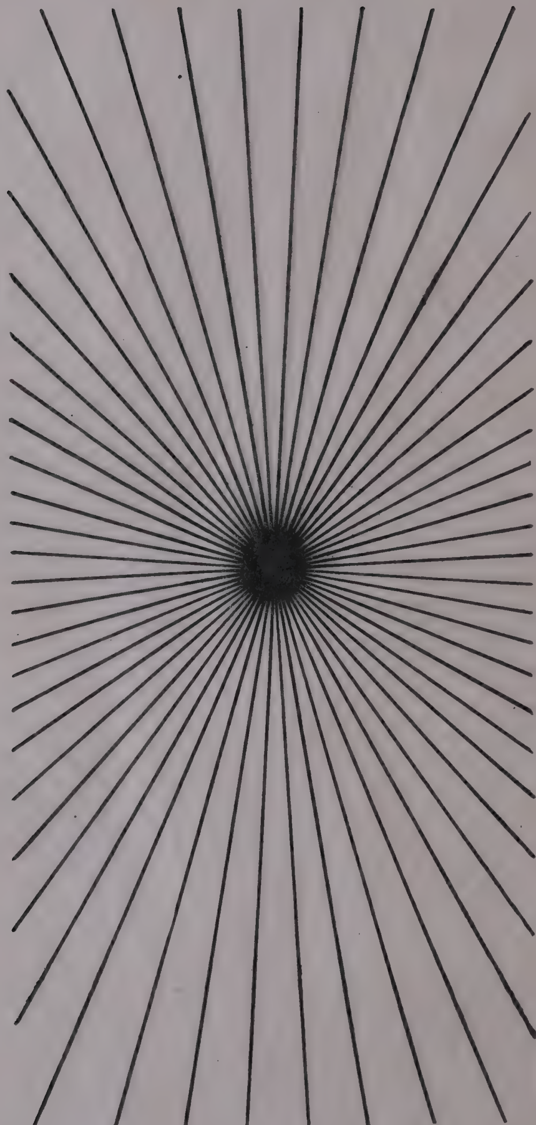


CHART 37



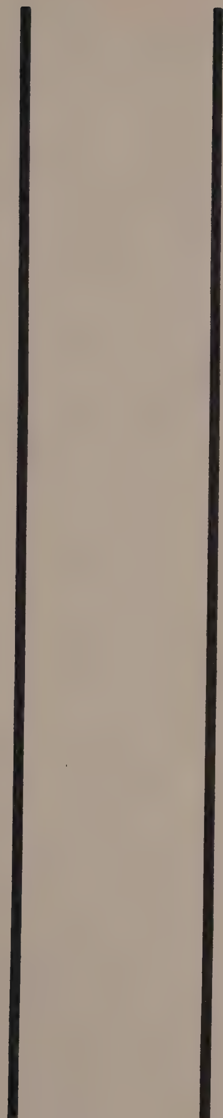


Chart 37

attention to the figures. Figure *a* on Chart 35 is a good example of this. The figure is composed of two pairs of horizontal lines separated by a space, in the middle part of which are three dots in line with the two lower horizontal lines. The attention that is directed to the dots is of secondary character and minor importance, compared with the major and primary attention given to the lines. These lines are, therefore, the lines of orientation of the figure, and the dots are exploited and located with reference to them. The two lines being close together, they are not perceived separately, but the space which they occupy is seen as a single space. This space is actually above the space of the dots, for the dots are on a line with the lower horizontals. The space of the dots, associated thus with the space of the horizontals, is attracted toward it; in consequence, the dots appear to be above what would be the continuation of the lower horizontals. The movement of attention is also easily observed in such figures as *g* on Chart 35. If the eyes are fixed steadily upon a point midway between the two parallels, and attention is thereby given to the parallels to the extent of ignoring the converging lines, the two verticals can be made to appear parallel. They appear to bend inward at the base, if we perceive them while distributing some attention to the converging oblique lines.

F. *Complicated associational illusion.* In reading this paragraph do you notice that the letters in the lines widely spaced and double leaded are apparently larger in size than the letters in the lines set in the usual way? Upon what do you think this apparent difference in size depends? Is it because, in a line set close, the eyes pass over the same number of letters in a shorter course? Or does the illusion arise from the belief that in two lines of equal length smaller letters must be used in the line containing the larger number? Or can the illusion be explained by a false reference of large letters to large spaces?

Experiment XX. **Complex perceptions, ideas, thoughts, feelings, and voluntary actions.**

A. Call to mind what you would think, feel, and do if you should see (1) a flash of lightning, (2) a case of diphtheria.

B. What is courage? Beauty? Space? Attention? Apperception? Mathematics? History? Geography?

C. What is your favorite picture? Why? What is the most beautiful building you have ever seen? Do you enjoy natural scenery? Why?

D. Do you believe in the gold or silver standard? Why?

E. Do you believe the people of the United States were justified in their treatment of the Indian natives of this continent? If you had been compelled to fight in the South African war on either one side or the other, would you have chosen to fight with the British or the Boers? Why?

To be asked and to answer a question may constitute a psychological experiment. The stimuli are the written or spoken words. The mind reacts to these stimuli with complex mental contents, memories, ideas, feelings, and groups of thoughts and feelings, which will constitute, in some cases, moral and other judgments. If you are asked, "What is courage?" the auditory perception of the words will be combined in your mind with memories of courageous action, numerous ideas associated with the manifestation of courage, and the feelings which you appropriately associate with a judgment of the worth and significance of this moral quality. These ideas, feelings, and impulses to action will furnish a clue to the mental and moral character of your mind. They will also reveal the point of view from which you regard courage, whether as a virtue or a vice, etc.

These questions and answers may be considered under five general heads: (*a*) complex perception; (*b*) conception, logical thought, and reason; (*c*) aesthetic appreciation; (*d*) political and social judgments; (*e*) judgments of right and wrong.

A. *Complex perception.* All may see the same flash of lightning. One apperceives a dreaded instrument of destruction and shows his orientation of this natural phenomenon by shutting the window and diving for the feather bed. Another apperceives an electrical display of great interest; from this point of view, he exploits or attentively observes his associated perceptions of the flash, its shape and color, the place where it comes to earth, the time that elapses between the flash and the clap of thunder. He will associate all of these perceptions with such ideas as he may be able to reproduce, respecting the phenomena and laws of electricity. Thus, as we are told, Franklin studied the lightning with his kite.

Another illustration is furnished by the physician and the so-called Christian Scientist, who may both perceive the same disease,—let us say diphtheria. A knowledge of the facts of medical science and practice leads the physician to view the disease as an infection caused by a specific germ whose ill effects may be opposed by an appropriate course of treatment. He therefore notes the time of the first appearance of the disease and the physical condition of his patient; he exploits all of his ideas on drugs and other remedies in order to form a judgment as to the proper treatment of the case. The Christian Scientist, on the other hand, views diphtheria as an idea. Believing all physical objects to be merely ideas in the mind and that any idea can be put out of mind by not thinking about it, he proceeds to treat the disease in accordance with this point of view.

B. *Conception, logical thought, reasoning.* When you are asked, "What is mathematics?" the mind reacts with ideas and thoughts which represent and summarize your past experience with arithmetic, algebra, and related branches of knowledge. The definition or description of mathematics or of any one of the terms found in question B involves: (1) an idea suggested in the first instance by the term; (2) ideas, thoughts, and feelings

associated with the initial idea; (3) the point of view which the individual takes toward the particular concept and toward its associated mental contents, and (4) a summary or synthesis of all the ideas most closely associated with the words. The orientation and exploitation of the ideas connected with a given term do not differ essentially from the orientation and exploitation of the parts of some external object. Psychology deals with abstract ideas and general terms as well as with perception. Logic is that branch of psychology which treats in detail of the analysis of ideas, and of their combination in associations or trains of thought called reasoning.

C. *Aesthetic appreciation.* The perception of some objects is associated with an agreeable feeling and an impulse of attraction; the perception of others with a disagreeable feeling and an impulse of repulsion. The associated feeling varies with the character and constitution of the individual mind. In consequence, different persons will call one and the same object beautiful and ugly. The individual orientation, from which proceeds the aesthetic feeling, is often not readily discerned. In many cases, reflection alone informs us of the reasons for our reacting, now with pleasure, now with displeasure, to the objects we call beautiful or ugly. Even upon mature reflection, so much doubt often remains, that, in popular opinion, there is no use arguing about matters of taste. This is equivalent to asserting that the point of view of the individual is final, or at least is the chief factor in determining aesthetic judgments. It cannot be maintained, however, that aesthetic taste is not susceptible of training. Change follows upon experience of, and familiarity with, those works of art and nature which the best minds agree in calling beautiful. With the increase in the number and quality of the ideas which can be associated in an individual mind with a given work of art or nature, comes a more developed point of view and a more expanded mental horizon, resulting in a higher level of aesthetic appreciation.

A broad education is as necessary to the enjoyment of a great poem, or painting, or musical composition, as it is to the comprehension of the principles involved in the many questions upon which the citizen of the modern state may be called to express an opinion or cast a vote.

D. *Political and social judgments.* Each student will probably apperceive the question of a gold *versus* a silver standard from the point of view of either a Democrat or Republican or Populist. Our habits of mind and the mode of acquiring our stock of ideas make it almost impossible to view these questions from any other standpoint than that of the people among whom we have been brought up. Many in the East cannot conceive of an honest man's favoring the ratio of sixteen to one, whereas many in the West believe that the adherents of the gold standard are merely seeking to increase unjust gains from the loaning of money. A political argument on the gold and silver question will exploit all the facts from the point of view held by the disputant. If the argument is to succeed in converting a man from the one opinion to the other, it must either change his point of view or bring new facts into association with those already known. The point of view of the grown man is generally too well established by his environment and mode of life to permit of much change. It therefore not infrequently happens that political arguments, in the form of popular addresses, attempting to exploit the facts from all points of view so as to hit the apperceptional tendencies of different minds, present many sophistical interpretations of the facts.

E. *Moral judgments.* Judgments of right and wrong are determined by the most persistent elements of our nature. By the character or personality of an individual, we generally mean the character portrayed in his conduct and in the moral principles to which he gives assent. In every expression of a moral judgment, involving the rightness or wrongness, the justice or injustice, of an action, the orientation or point of view of the

individual pronouncing the judgment is the deciding factor. That the point of view of the same individual may differ even with respect to the same actions can be demonstrated by the moral judgments given in answer to the questions of group E. Some persons will regard the action of a nation from the same point of view from which they regard the actions of individuals. On the other hand, there are those who judge the conduct of an individual much more rigidly than they do that of a nation or race. When we think of the sufferings of individual Indians, we cannot help feeling that injustice was often inflicted in driving them from the land they originally occupied. There are even those to whom the peaceable purchase of land with worthless beads seems a reprehensible act. To other minds, in view of the historical development of this continent, it appears a greater wrong and injustice to have left undeveloped, in the hands of a few thousand uncivilized natives, the immense natural resources that have proved of such signal service to millions of people. The phrase "be an American," in connection with questions of foreign policy, generally means orient and exploit the political issues from the point of view of national morality rather than from that of private morality. In judging the merits and demerits of the South African war between the British and the Boers, we in this country tend to judge the British from the generally higher standard of private morality because the national point of view is not involved. In the story of the Walrus and the Carpenter, Lewis Carroll has admirably portrayed a type of mind which can manifest at one time contrasting points of view. The situation, as presented in the poem, involves the question of the moral obligation of the Walrus to the Oysters, whom the Walrus and the Carpenter had invited one fine night to a promenade upon the beach. The Carpenter has but a single ethical standard ; to him the oysters are food only. But the Walrus finds that they appeal to his moral sensibilities as well, for

"It seems a shame," the Walrus said,
"To play them such a trick,
After we've brought them out so far,
And made them trot so quick!"
The Carpenter said nothing but,
"The butter's spread too thick!"

"I weep for you," the Walrus said:
"I deeply sympathize."
With sobs and tears he sorted out
Those of the largest size,
Holding his pocket-handkerchief
Before his streaming eyes.

With the conclusion of this chapter, we reach a turning point in our study of mental processes and contents. Hitherto we have considered mental contents, the component parts of which were readily ascertained. In the results of the experiments of this Manual, each and every one of us could directly observe what was brought into actual existence in his own mind. This method of study is called *introspection* or *psychical observation.* But we have not only observed what was in our minds, we have dissected or *analyzed* the mental contents into their component parts. *Introspective* or *psychical analysis* informs us of the associations of simpler contents or elements, which constitute distinctive and discrete perceptions, memories, ideas, thoughts, feelings, etc.

Psychical analysis, however, is able to give only a limited amount of information as to the constitution of mental contents. The conclusion of the first experiment of the Manual is an inference based upon more than what is given by the direct observation of the mental contents themselves. The figure of the staircase on Chart 1 gave rise to a perception of staircase from above and a different perception of staircase from underneath. Because one and the same physical stimulus acting upon the same sense organ produces two different

perceptions, we infer that what is unlike in the two perceptions is to be attributed not to the stimulus nor to the sense organ but to the mind's own activity. The knowledge that we have two perceptions is a *psychical* fact obtained from introspective observation; the knowledge that we have but one stimulus is a *physical* fact, obtained from objective or physical observation. The knowledge that the one stimulus gives rise to two perceptions is a *psycho-physical* fact; to make use of this knowledge, as we did in ascribing a simple part of the perception to the stimulus and a more important part to apperception, is to employ the method of *psycho-physical analysis.*

From another experiment, we learned that the retinal image of an object is inverted and that it varies in size with the distance of the object. The physiological processes excited in the retina, consequently, have only the merest suggestion of correspondence with the physical stimulus. Nevertheless the perception is fairly constant and closely approximates to our general knowledge of the object. Here again we inferred that the meagre result of sensation was transformed by the activity of apperception. This inference correctly follows from our knowledge of what takes place in the retina and of what is actually existing in the mind. This knowledge is a *psycho-physiological* fact. To ascertain the relative contributions of sensation and apperception, it is necessary for psychology to resort to *psycho-physiological analysis.*

Association varies from the loosest kind of combination to the most intimate fusion and synthesis of elements. In the preceding chapters, we have met with perceptions representing many different degrees of combination. We have, however, given chief consideration to those which are relatively less closely combined, and thus permit of direct and ready ascertainment. The more complicated a perception and the more intimate the combination of its component parts, the more difficult will it be to ascertain its constitution by introspective analysis alone.

Perceptions of space are among the most complicated that psychology is called upon to analyze and explain. A systematic examination of what is actually received from the eyes and from other sensory sources will alone enable us to comprehend the genesis of these highly complex perceptions. The next chapter enters upon a study of the perception of space. Although we shall rely as much as heretofore upon the results of introspection, the analysis will appear more evidently psycho-physiological.

The sense organs and all physiological processes belong to the world of physical objects. In the broadest meaning of the word "physical," the analysis of mental contents with reference to physiological processes may be considered to be psycho-physical. It is helpful, however, to make as obvious as possible the distinction between the physical facts, concerning the human body and its processes, and the physical facts of the extra-corporeal world and its stimuli. In analyzing some of our mental contents, more assistance is afforded by a knowledge of related physiological processes than by the knowledge of the physical stimuli. This is the case with visual perceptions. Contrariwise, other mental contents can be better analyzed and explained, if they are studied in relation to the physical stimuli which occasion them. This is the case with auditory perceptions. Some mental contents, therefore, are more readily approached for the purpose of systematic investigation by the way of psycho-physiological analysis and others by the way of psycho-physical analysis. An adequate explanation of the origin and constitution of any given perception, simple or complex, requires that the several results of introspective, psycho-physiological, and psycho-physical analysis be accorded their due measure of consideration.

CHAPTER IV

PERCEPTIONS OF SPACE

Experiment XXI. **The eccentric location and projection of touches.**

Close the eyes and tap the floor with the tip of a cane, or move the point of a lead pencil over a book or table. Do the sensations of contact seem to come from the tip of the cane and point of the pencil?

Press vigorously upon one end of the cane or pencil, the other end being fixed immovably. Are the sensations of contact now more distinctly located in the hands and arms?

Touch the hair of the head. Do you feel the touch in the scalp or in the hair? Touch the table or any object with the finger-nail. Touch a pencil lightly to the teeth. Bite on the pencil. Touch single hairs on the back of the hand or fingers, on the inner and outer forearm. Where are the touch sensations located?

There are neither sense organs nor nerves in the hair and finger-nails. A sensation of touch which is due to the excitation of nerves in the tissues at the base of the hair and nails is perceived as a touch or contact located at the outer ends of these structures. When a stick is held in the hand by one end, and its tip is gently moved over an external object, we feel as though we were actually touching the object at the other end and receiving a sensation directly from it. These sensations are not located in the hand, where the stick is grasped, because at the time we are having vivid perceptions of the external object at the far end of the stick. If the hair is touched, we know through experience that the object is not in contact with the scalp but with the ends of the hair. Attention is directed to all

our knowledge of the stimulus and not to the particular sensation alone. To locate the touch stimulus or touch sensation is to associate it with other sensations and with perceptions and ideas simultaneously present in consciousness. This association may cause the sensation to appear to be *projected* outwardly, or eccentrically, from the body to the external object.

EXPERIMENT XXII. **The "local sign" of touches.**

Let the experimenter touch you with a pencil point on several places: on (*a*) the forehead; (*b*) the cheek; (*c*) the backs of the two hands; (*d*) the finger tips. Describe as well as you can the particular quality of the touch sensation in the different localities and tell what are the associated perceptions and ideas which enable you to recognize the place touched. For example, how do you tell your right hand from your left? How do you know whether the forehead or the cheek has been touched? Do you notice that you refer touch sensations to prominent members of the body, *i.e.*, locate a touch on the cheek as near the eye, nose, mouth, or ear?

When a spot on the skin is touched, the sensation that follows has a distinctive character or *quality*. When two sufficiently separated spots are touched, two qualitatively different sensations result. Touch sensations are therefore said to differ in *local quality* or *sign*.

This difference in quality is due in part to differences in the structure of the portions of the body touched. A touch on the skin over a bone will differ from a touch on the skin over a muscle or tendon. Furthermore, the sensation of touch is usually a combination of several distinguishable sensations; even when it appears to be a simple, *i.e.*, an unanalyzable, mental content, it represents the mental result of a *fusion* of several physiological processes. A touch sensation is never the result of the excitation of a single nerve fibre of touch. Even

if we suppose that a single nerve fibre could be excited individually to give rise to a simple sensation, it is to be assumed that the nerves of touch in different parts of the body would give somewhat different sensations.

Under what conditions is it possible, when we receive qualitatively different touch sensations, to localize the respective points of the skin that have been stimulated? A touch sensation always brings with it into mind a more or less vague perception or idea of the region of the body to which the point stimulated belongs. A touch on the back of the hand awakens not merely the sensation of a single touch, but also a perception or "feeling" of the whole hand; in other words, the touch sensation has a background, more or less vague, of the sensations and perceptions with which it has been associated in past experience. Thus a given touch sensation is generally located by referring it to some prominent member of the body; for example, it may be described as being on the back of the forearm at a certain distance from the wrist or elbow.

This perception of the spacial relations of a touch on the forearm is developed from the mental results of the movement of the opposite hand over the skin from the wrist to the stimulated point. The immediate result of a movement of one part of the body over other parts is an association of kinaesthetic sensations from the moving part with sensations of touch from points of the skin successively stimulated. The permanent result of repeated movements is a mental chart of a locality of the body, formed from the memories of these associated sensations of motion and contact.

The associated kinaesthetic sensations may not be very prominent. It is often difficult to tell how one distinguishes the right hand from the left, and yet one may never be confused as to which is which. The right hand is used so much oftener than the left in manual activities that it is brought forward instinctively and readily whenever called upon, and

is distinguished from the left by a vague sensation or "feeling" of greater facility of movement. What has been said of the right applies of course to the left hand, in those who are born left-handed. Right-handedness is a natural characteristic of at least ninety persons in every hundred. Not more than five in every hundred are left-handed. Very few persons are really ambidextrous. Such persons often have great difficulty in telling the right hand from the left; but one who is pronouncedly either right-handed or left-handed finds that the difference in kinaesthetic quality, resulting from the different use of the two hands in the past, assures immediate recognition.

Kinaesthetic sensations also play an important part in assigning distance and location to objects external to the body. When an object is thought to be at some given distance, we generally mean that we should have to walk or otherwise move "so much" in order to reach it. It is still customary in some parts of the world to reckon distance in terms of the time it would take to traverse the distance. Many persons are even unable to give measurements in terms of inches or of feet, but will move the hands apart to indicate the distance, saying, "It is so long." We tend to think of near-by objects as within reach or out of reach; we experimented during many months of infancy to fix this essential difference of spacial perceptions in mind. The location of more distant objects is also given primarily with reference to our bodies. Thus if one thinks of the four walls of the room and then of the door, he will think of these as though he were turning the head and eyes or body toward them. The spacial exploitation of the objects of the environment is ego-centric, that is, each object is referred to the place at which we happen to be or to some place in which we think ourselves. If we try to think of the location of some distant town, we may, it is true, refer its locality to the points of the compass, but north, east, south, and west have no meaning until we have placed ourselves in some relation with these directions.

The retina of each eye is a sensitive surface in many respects analogous to the surface of the skin. The light rays, which directly stimulate it, may affect one point or be diffused over many points. The central point of the retina, the fovea centralis, is distinctive; from it alone clear vision results, and the mechanism of the eye is so constructed that a stimulus acting upon the peripheral portion initiates reflexly the contraction of the muscles necessary to move the eye so as to cause the stimulus to act upon the fovea centralis. Through this movement of the eye, the stimulus acts successively upon all points of the retina situated between the fovea and the part first affected. The result is a continuous series of retinal sensations, each possessed of a distinctive local quality or sign, and each given its location in the retina with reference to the more prominent sensation of the fovea. The series of retinal sensations has associated with it a continuous series of kinaesthetic sensations from the movement of the eyeball in its socket. The associated retinal and kinaesthetic sensations furnish the basis for an independent development of visual perceptions of space. These, however, are usually developed only in connection with and in dependence upon the more general space perceptions constructed from associated sensations of touch and general bodily movements.

Experiment XXIII. **The projection of visual images beyond the eyes into the external field of vision.**

A. *Retinal images and shadows of external objects.* Take a black card and prick a hole in it with a pin. With one eye closed, hold the card, as close as convenient before the other eye, in such a position that you can look through the hole at the sky or some distant bright object. Hold the pin with the head up between the screen and the eye and almost touching the eye. Move the pin to and fro, up and down, so that it appears to pass across the hole in the card. Observe the apparent position of the pin. Is it right

side up? Does it seem to be nearer than the card or farther away? Does the image move across the opening of the card in a direction contrary to the actual movement of the pin?

The visual perception of the spacial attributes and relations of an object is dependent, in the first instance, upon sensations that are the mental results of an image of the object formed on the retina of each eye. The refractive properties of the lens, by which the retinal image is inverted with reference to the external object, have already been considered (see page 18). The retinal image itself is never perceived. It is only the physical medium through which the object stimulates the rods and cones of the retina, and finally the optic nerve and brain, so as to give rise to a visual perception. The retinal image is in some respects similar to a shadow of the object. Both are surfaces and both vary in outline and size with the form and size of the object. From a shadow we can frequently infer the form, size, distance, and location of the object. But the interpretation of a shadow is fraught with many difficulties and possibilities of error, for the form and size of the shadow depend not only on the form and size of the object but also upon the distance and direction of the source of illumination. The *retinal image* varies not only with the actual form and size of the external object but also with its distance from the eye and the part of the retina on which the image happens to fall. The *visual image*, *i.e.*, the perception or mental image of an object, corresponds much more closely with the actual object than does the retinal image. The sensations which are due directly to the retinal image will vary in number and local quality, depending upon the size, form, distance, and location of the object. These sensations constitute an important part, but nevertheless only a part, of the visual image, for this is the perception of an object of definite spacial attributes and relations. The retinal sensations act as a mental cue for

the association of other sensations, perceptions, memories, and ideas, from the combination of which the complete visual image is constructed.

Let the continuous outline of a pin, in the accompanying diagram, represent any object from which rays of light are reflected and brought to a focus on the retina of an eye. The head of the pin will cast its image at the end of the ray line, represented by the continuous line extending from the pin head to the retina. The retinal image of the pin point will lie above that of the pin head at the end of the ray line (the continuous line), extending from the pin point to the retina and crossing the ray line of the pin head in the lens. The visual image of the pin is located in the external field of vision, beyond the eye, at or near the locality of the object, and is not inverted with reference to the object as is the retinal image. The visual image of the pin head appears to the mind as though it had been projected outward from the retina along a line which has practically the same position as the ray line of the retinal image. This line is called the *projection line* of the visual image; it is represented by the broken line extending parallel and close to the continuous line. As the broken line could not be represented over the continuous straight line, it is drawn in the diagram a short distance to one side. The visual image of the pin point is likewise projected along a line which is practically coincident with the ray line of its retinal image (the broken line adjacent to the continuous line). Visual images are therefore seen as though projected outward into space, point for point, through the lens along the ray lines that give rise to them. This statement expresses the fact that the inverted

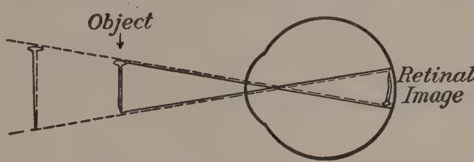


DIAGRAM VIII. The formation of retinal images and the projection of visual images.

relation of the retinal image to its object has no significance for the mind in comparison with the actual relations subsisting between objects, as these have been habitually perceived and located through the different senses. Projection is a visual habit of associating the retinal sensations with other mental contents, whereby the visual image acquires a greater semblance to the external reality than is possessed by the sensations that can be directly referred to the stimulation of the retinal image. An experiment was recently made with a pair of glasses that caused the retinal image to be right side up with reference to the external object. For a time the subject wearing these glasses perceived objects as though they were inverted. He frequently blundered in attempting to reach for things within his field of vision. In a short time, however, perception and movement became accommodated to this change in the relation of the retinal image to the external object, and the usual perception of their actual relations was reëstablished.

The visual image of a shadow on the retina will be projected as though the shadow were a retinal image. Diagram IX represents the conditions and results of the present experiment

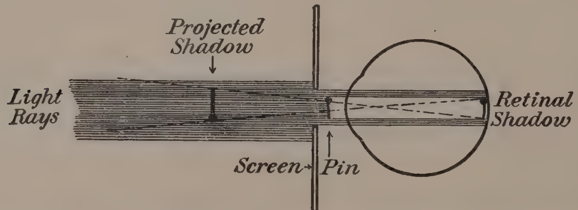


Diagram IX. The projection of the visual image of a retinal shadow.

with the shadow of a pin. The pin is held close before the eye; beyond the pin is a screen with a small opening. Rays of light falling upon the screen are represented by the horizontal straight lines. Some of these rays pass through the opening of the screen and, entering the eye-globe through the

pupil, illuminate the retina. The pin is an obstruction, as is the screen, in the pathway of these rays of light and casts a shadow of itself upon the retina. This retinal shadow will, of course, be right side up with reference to the real pin outside. In consequence of the tendency under consideration to project a visual image point for point along the ray line of each point, the head of the shadow pin will be projected along the broken line represented in the diagram. This line has the position of what would have been the ray line of a pin head formed as a retinal image and not as a shadow. A point on the shaft of the pin will be projected along a line which crosses the projection line of the pin head in the lens. The actual pin before the eye and behind the screen will consequently give rise to the perception of a dark, shadowy pin inverted. This shadow pin will generally be projected beyond the screen, and will then appear as though it were a pin viewed through the opening, larger than the real pin and at a distance of four or five inches from the eyes.

So far as the lines of projection would indicate, the visual image might be projected to almost any distance. The farther the image is projected, the larger will the object appear to be. Visual size and distance are reciprocally related. If the one is established, either from previous knowledge of the object or from associated kinaesthetic sensations, the other will invariably be determined in consequence, no matter what the actual size of the retinal image may be. In the illustration of Diagram VIII, the visual image is projected to its actual position in space rather than to some other distance, as, for example, that indicated by the broken outline of the pin. There will then be seen a bright shining pin of the standard size, which will be correctly located. Of the various factors that serve to determine this spacial perception, we have considered the retinal image and the projection of its mental correlate, the visual image. The conditions that determine the distance to

which the visual image shall be projected along the diverging projection lines and the resultant perception of size, will be considered in the experiments that are to follow. If these conditions do not positively determine the distance to which the visual image shall be projected, there is a tendency to project the image to an indefinite and variable distance, in many cases to the distance of most frequent accommodation, *i.e.*, the reading distance.

B. *Entoptic shadows.*

1. Have you ever observed black or colored specks moving across the field of vision, as, for example, when looking at the sky? If so, describe their appearance, movement, and apparent position with reference to the eye.

2. Sit in a dark room, about five feet in front of a white wall; close the left eye and look with the right eye toward the wall without moving the eye. Hold a lighted candle in the right hand two or three inches in front of the right eye and off to one side of the line of sight, so that the candle throws its light through the pupil upon the retina, without being itself clearly visible. Move the candle about slowly. Do you see the projected image of the retina with its blood vessels, yellow spot, and blind spot in outline? Draw and describe what you see.

The dark specks are the so-called *muscae volitantes*, literally "flying mice." They are due to particles in the vitreous humor which cast shadows upon the retina. Looking at the ceiling, these spots will be large and appear at some distance. If the eyes are directed to some surface close at hand, as a sheet of paper, they will appear small, and to float over the surface of the paper. A projected image of the retina will contain the shadow outline of the blood vessels of the innermost layer; the image will have the appearance of the retina as represented in Diagram VI, page 48. All structures of the retina, intercepting the rays of light before they reach the rods and cones, cast shadows

upon the sensitive layer of the retina. When the shadows become objects of perception, the shadow images are projected outward to a distance which is determined by the distance of that object in the field of vision which is receiving attention at the moment, namely, the plane of the ceiling or of the paper. This plane of attention, to which all visual images are referred, unless certain definite conditions cause them to be projected to a greater or less distance, is called the *plane of projection.*

EXPERIMENT XXIV. **Monocular accommodation.**

A. *The kinaesthetic sensation of monocular accommodation.* Stand a few feet in front of a window. Close one eye and hold a finger at a distance of about six inches before the other, and at right angles to one of the horizontal bars of the window. Look at the window bar and observe the appearance of the finger. Look at the finger and observe whether the window bar becomes dim and diffused. Hold the finger at arm's length before the open eye; move it slowly toward the eye until it is against the lashes; move it slowly away until it is again at arm's length, fixating continuously with the open eye. Does the sensation of effort and eye strain increase as the finger is moved toward the eye, and decrease as it is moved away from the eye?

B. *Diffusion due to imperfect accommodation, and the relation of apparent distance and size to the definition and diffusion of the retinal image.* Close one eye and accommodate the other eye for a fine needle or pin held vertically before it and about eighteen inches distant. Move the needle slowly toward the eye, continuing to accommodate for it. When the needle is brought within about six inches of the eye, does it become dimmer, more diffuse, and apparently larger?

Prick a hole in a card with the needle. Hold the card close to the eye and look through the hole at the needle as before. Can you now bring the needle nearer to the eye without its becoming

indistinct and diffuse? What effect has the small aperture of the card upon the apparent size of (1) the needle near at hand, and (2) a distant object, when the eye is accommodated for the nearer and when it is accommodated for the farther object?

Let *N* in Diagram X be any point of an object near the eyes. This point will reflect rays of light in all directions, a large bundle of which (the five diverging lines) will pass through the pupil to the lens, by which they will be bent or refracted, and brought to a focus. If the heavy outline of the lens represents a medium curvature, the rays of light will be brought to a point at some distance behind the retina. Where these rays are intercepted by the retina they will be spread over a circular area, represented in the diagram by the amount of space covered by the five lines. These circular areas, due to imperfect accommodation of the lens for the distance of the object, are called *diffusion circles*. As every point of the object gives rise to a diffusion circle, the total retinal image will be indistinct, diffuse, and large. The external object may, under such conditions, appear at a greater distance and larger than it really is.

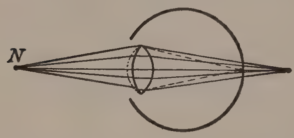


DIAGRAM X. Diffusion circle from an imperfect accommodation of the lens for a near point.

If the rays from the point *N* are to be brought to a focus on the retina, the curvature of the lens must become greater, *i.e.*, assume the form indicated by the dotted line. When this is accomplished through the vigorous contraction of the ciliary muscle, every point of the external object will cast a corresponding point upon the retina. The retinal image being thus clearly defined, the visual image will appear correspondingly distinct. The apparent distance of the object, *i.e.*, the distance to which the visual image is projected, depends in part upon the size and definition of the retinal image, but in part also upon

the particular quality and intensity of the kinaesthetic sensation received from that amount of contraction of the ciliary muscle which is necessary to produce the focusing of the image upon the retina.

In Diagram XI, let *D* represent a distant point. The rays from this point will be brought to a focus, when the lens is in a condition of medium curvature, somewhere between the lens and the retina. Beyond this point the rays will diverge, giving rise to a diffusion circle upon the retina. If the point is to be focused upon the retina, the ciliary muscle must relax its tension and the lens be brought to a condition of less curvature through the outward pull exerted by the suspensory ligament and ciliary processes (see the description of the mechanism of accommodation, pages 32–35).

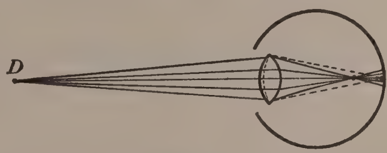


DIAGRAM XI. Diffusion circle from an imperfect accommodation of the lens for a distant point.

The screen with a small hole through which an object is viewed cuts off the outer rays and diminishes the area of the diffusion circles. Not only the distinctness of the object, but also its apparent size and distance, will be modified by the relative diffusion of its retinal image.

C. *The near and far limit of accommodation.*

1. Prick in a card two small holes so close together that both are within the diameter of the pupil. Close one eye and hold the card before the other eye, with the holes in a horizontal line. Look through the holes at a needle held vertically at a distance of fifteen inches. Fixating the needle steadily, move it toward the eye until two images of the needle are seen, one in each hole. This is the *near limit* of accommodation.

2. Stick the needle upright in a piece of cardboard and move away from it, until two images are seen, one in each hole. This is the *far limit* of accommodation.

3. Hold the needle at a distance of ten inches and fixate it through the two holes, so that a single image is obtained. Look at some distant object. Does the needle appear double? Are the double images dimmer than the single image? Stop the hole to the right; which image disappears? Fixate some object nearer than the needle. Are the images double? Stop the hole to the right; which image now disappears?

4. Determine the near and far limits of accommodation, when the needle is horizontal and the two holes are in a vertical line. Compare these limits with those obtained above.

5. Prick in a card four or five holes close together, so that all are within the diameter of the pupil. Hold the card and the needle as directed above. Fixate the needle; is the image single? Fixate a distinct object; do you see as many images as there are holes in the card?

If the production of diffusion circles has been understood, there will be little difficulty in comprehending the results of this experiment. Let *F*, Diagram XII, represent a point from which rays of light proceed to the lens to be first refracted and then focused at some point behind the retina. If some of these rays are cut off by the screen and only a few are permitted to pass through say two openings in the screen, these rays will continue through the lens as two distinct bundles, to fall upon the retina as two separate diffusion circles, or images, of the external point. When the lens (the dotted outline) is accommodated for the point, these two bundles of rays will be more refracted and will unite at a point upon the retina, as shown by the two groups of dotted lines. With the screen in position, the eye may be alternately accommodated for the needle or for an object at a greater or less distance. In the first

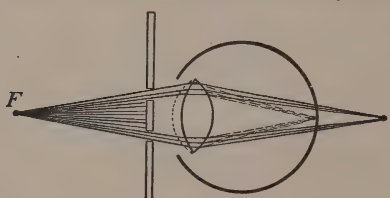


Diagram XII. Double images of diffusion due to imperfect accommodation.

case, a single clear image of the needle will be seen, and in the second case, two diffused and larger needles will appear through the screen. If the number of holes in the screen is four or five, and yet all the holes are so arranged that they are within the diameter of the pupil, they will permit an equal number of separate bundles of rays to pass to the lens. The bundles of rays will give rise to separate diffusion images if the object is viewed without accommodation, but to a single image if the curvature of the lens is adapted to the distance of the object.

The lens is not the only structure of the eye which refracts the light rays during their passage from the outer surface of the cornea to the retina. The cornea, the aqueous humor of the anterior chamber, and the vitreous humor, all contribute to the refraction to which the rays are subjected. The amount of refraction is dependent upon the substance of these various structures and upon the curvature of their boundary surfaces. The refraction of these structures is constant; that of the lens is variable, depending upon the accommodation of the curvature of its anterior surface (to a small extent of its posterior surface also) to the distance of the object. When the ciliary muscle is relaxed, the refraction of the lens added to that of these other structures is just sufficient, in an eye that is considered normal, to focus parallel rays, *i.e.*, rays from an infinite distance. Such an eye with its ciliary muscle in a state of maximum contraction is also able to focus rays from a point at an average minimum distance of 10–12 cm. (4 inches). These limits of accommodation are much greater than the practical limits of muscular adjustment; the ciliary muscle is, indeed, completely relaxed in accommodating for objects not more than 65 metres (200 feet) from the eye. The function of the kinaesthetic sensation from the ciliary muscle, in determining the distance to which a visual image shall be projected and in forming the consequent judgment of the distance of the object, is restricted to a much narrower range of distances than would appear from the

mere statement of the normal eye's limits of accommodation. The near-sighted or myopic eye has its most distant point of accommodation much nearer than that assigned above as the far limit of the normal eye; it is only with the near-sighted eye that a far limit of accommodation can be obtained by the method of this experiment.

The structure of the lens, cornea, and other refracting media may be such that the amount of refraction is not equal in all meridians. The amount of refraction, for example, may be greater in the vertical than in the horizontal meridian. This will make it impossible for an eye to be exactly accommodated at one time for vertical and horizontal lines at the same distance. This defect of the eye is called astigmatism.

Experiment XXV. **Single perceptions from double sense organs.**

Click two coins near the head of a subject, seated and having his eyes closed. Try at different positions in the prolonged median plane of the head and compare results with those obtained in positions to the right and left of such plane. Compare the subject's accuracy in the location of sounds coming from behind and from in front of the ears. Be careful that the subject is not assisted by the hearing of sounds made by the moving arms. What seem to be the conditions for the correct and false localization of sound stimuli?

A difference in the relative intensity of the sensations obtained from the right and left ears seems to determine the localization of a sound to the right or left respectively. Errors are frequent when the sound stimulus is in the median plane, because its intensity is then the same at both ears, and the two sensations are consequently of equal intensity also. When we locate a sound as coming from the right, we do not perceive two sound sensations but only one, and yet we have two ears, each

receiving its own stimulus. It is impossible to decide whether we should regard this single perception as a fusion of two sensations or of two physiological processes before they give rise to the single perception.

A similar fusion of two sensations, or of two physiological processes as the case may be, in a single perception can be demonstrated also in the field of touch. If the middle finger is crossed over the index finger so as to bring the tip of the middle finger on the thumb side of the index finger, a bullet, marble, or pencil may be inserted between the ends of the two fingers thus crossed. The subject will then feel as though he were being touched by two objects. If the same object touch two adjacent fingers in their normal position, he will, even with the eyes closed, feel but one object touching him. The two different surfaces stimulated should give rise in both cases to two sensations. But the two sensations from surfaces habitually stimulated by one and the same object are fused in a single perception of the object. It requires some unusual position of the two fingers to give rise to what is the more primitive double perception.

This fusion is a selection, by attention, of one element of the complete perception. The selection is readily observed if one touches with the tip of his own finger various portions of the body. The resulting sensations will seem to come either from the tip of the finger or from the part of the body touched, depending upon which is given attention at the moment. Those sensations which fail to gain much attention may drop out of consciousness. They are said to be *suppressed* or *inhibited*.

The sense organ of vision is a double one. Each eye has its own retinal image of the object of perception. Under certain conditions, a visual image or perception of the object is obtained from the retinal image of each eye; under other conditions, the two retinal images give rise to a single perception of the object.

EXPERIMENT XXVI. **Double visual images.**

A. *Displacement of one eye from the position of binocular coördination.* Look at any object. Do you observe one or two images of the object? With the finger, gently press the eyeball out of its ordinary position. Do you then see one or two images of the object? If two, which is the more distinct — that belonging to the eye subjected to pressure or that of the other eye? If you always receive an image of the object from each eye, why do you get double images only when you displace one of the two eyes from the position of binocular coördination?

Let the continuous outlines of the two eyes (Diagram XIII) represent the right and left eyes both directed upon the same object, *i.e.*, the point *F*. The lines of sight of the two eyes (not represented in the diagram) converge to meet at the locality of the point (see page 38). The two eyes are then in binocular coördination. It is only when the eyes are in this position with reference to an external object, that we can obtain, through the use of both eyes at once, a single and distinct perception of the object. The ray lines of the point *F* (the solid lines in the diagram) pass directly to the centers of the two retinae. A single image of *F* is seen, under these conditions, at the locality of *F*. In producing a single visual perception, the two visual images act as though they had been projected outward to coincide at the locality of *F*. The projection lines (broken lines in the diagram) which represent this fact have practically

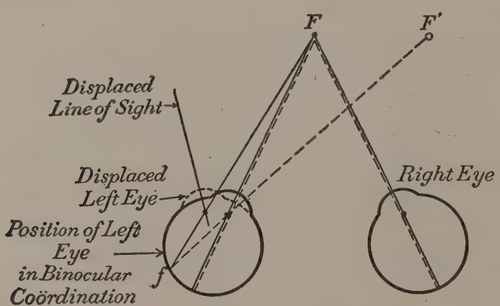


DIAGRAM XIII. The production of double images by the displacement of one of the two eyes.

the same position as the ray lines (see page 115). When the two eyes are in the position of binocular coördination, both being directed upon a given point, the projection line of each eye's visual image of the point coincides with the ray line of its retinal image and also with the line of sight of the respective eye. Under ordinary conditions of binocular coördination, the two visual images are projected to the common point of intersection of the ray lines, projection lines, and lines of sight of the two eyes; as a consequence, the two images coincide at this point and combine in a single perception.

If one eye-globe, say the left, is displaced so that its line of sight is directed off to the left of the point (indicated in the diagram by the dotted outline of the cornea), the image of F must fall upon the retina somewhere to the left of its center (at f), at a distance determined by the amount of displacement to which the eye has been subjected. Two visual images of the point will then appear, the image belonging to the left eye being to the right of that belonging to the right eye. The distance between these two perceptions of the point will be proportional to the distance of the retinal image of the left eye from the fovea. The ray line of this retinal image is the continuous line Ff. If its visual image were projected in accordance with the habit of monocular vision, the projection line would coincide with the ray line, and the visual image of the left eye would coincide with that of the right eye at the locality of F. The result of this experiment shows that the visual image of the left eye appears at F' to the right of F; the visual image must have been projected in a manner not determined by the habit of monocular vision. If the left eye were binocularly coördinated with the right, a retinal image at f would give the perception of a point located along the line fF' (at F'); for in this position of the left eye, it is a point at F' which is usually the cause of a stimulation of the retina at f. In the present case, the retina of the left eye is stimulated at f, because

the whole eye is displaced, but the image is projected as though the retina had been stimulated with the left eye in the position of binocular coördination. The left eye is stimulated independently, but the mental result of such stimulation is determined by the habit of the two eyes as a single, although binocular, mechanism. A habit of monocular vision gives way before a habit of binocular vision, when unusual conditions compel a choice between the two.

B. *The convergence of the two eyes upon a distant object will cause all objects nearer to the eyes to give double images.*

1. Hold up the forefinger of the right hand about ten inches in front of the eyes and look beyond the finger at the wall. Do you observe two transparent or shadowy images of the finger? If you do not get the double images readily, close each eye alternately and observe the respective places on the wall against which the finger is projected. Then open both eyes and observe the two shadowy images at both places.

2. Point with the forefinger of the right hand at some distant object, holding the hand just a little in front of the nose. Look with both eyes at the object beyond the finger. Do you see two images of the pointing finger? Which of the two images is pointing at the object? To which of the two eyes does this finger belong?

Many persons have great difficulty in perceiving the two images. One or the other of the two is overlooked or suppressed. In some persons, it is usually the image of the right eye; in others, that of the left. If one of the two retinal images falls on a more sensitive locality of the retina than the other, its visual image will gain attention and the other is likely to be suppressed. A few persons will be quite unable, even after many trials, to get double images, and yet the two images are always on the retina, and two perceptions are usually present in consciousness, even though one may be so indistinct as to appear below the threshold of perception.

C. *Convergence upon any one object causes double images of objects nearer and farther than the object fixated.* Hold up the two forefingers directly before the eyes, one in front of the other at a distance apart of ten or twelve inches. Fix the gaze on the farther of the two fingers. Does it appear single and the nearer double? If so, close the right eye and see whether the right or left image of the nearer finger disappears. If the right-hand image disappears, it belongs to the right eye. Close the left eye to determine which of the two images belongs to it.

Fix the gaze on the nearer finger. Do you get double images of the farther finger? Which image belongs to the right eye, and which to the left?

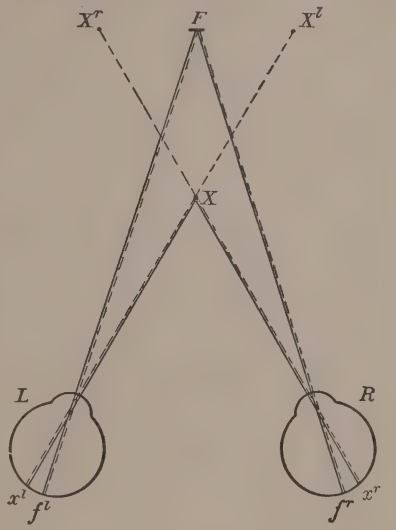


DIAGRAM XIV. The heteronomous doubling of objects farther than the point of binocular fixation.

Diagram XIV represents the two eyes binocularly fixated upon the point F. The ray lines from F pass to the centers of the two retinae, f^r and f^l, and the projection lines pass outward along the same lines and meet at F. X represents any point nearer than F, the point of fixation. The ray line from X to the right eye will fall upon the point x^r of the retina, to the right of the fovea centralis. The projection line of the visual image of this point will follow the direction of the ray line and pass outward through and beyond the point X. The image of the right eye will therefore be seen somewhere along the projection line (the broken line). The distance to which this image is projected is determined within vague limits by the plane of the fixated

point F. In the diagram, the location of the projected image is therefore represented as X^r to the left of F. The ray line from X to the left eye will fall upon x^l, to the left of the fovea centralis. The visual image of this point will be projected outward along its ray line, also as far as to the plane of the fixated point F (X^l of the diagram). X will therefore give rise to two visual images located in the plane of projection to the right and left of the point of fixation. The right-hand image will belong to the left eye, and the left-hand image to the right eye. The point is then said to be *heteronomously* (of unlike name) doubled.

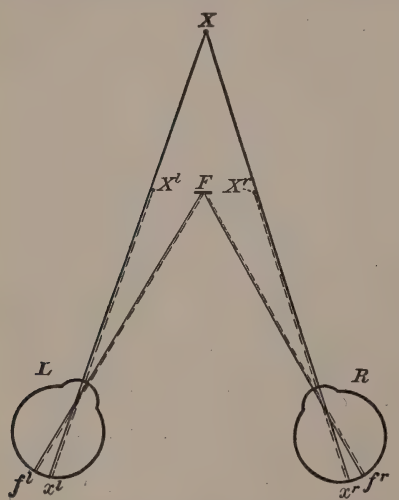


Diagram XV. The homonomous doubling of objects nearer than the point of binocular fixation.

Diagram XV represents the eyes converged binocularly upon F and receiving retinal images at the same time from the point X beyond the fixation point. The ray line from X to the right eye will cast its image, x^r, to the left of the fovea centralis, and the visual image will be projected outward to the plane of F. The ray line of X, passing to the left eye, will cast the retinal image, x^l, to the right of the fovea centralis, and the visual image will be projected outward along this line to the plane of fixation. X will therefore give rise to double images, X^r and X^l, to the right and left of the point of fixation; the right-hand image will in this case belong to the right eye, and the left-hand image to the left eye. A point more distant than the point of fixation therefore gives rise to *homonomously* (of like name) double images.

It must not be supposed that the plane of fixation, to which the double images are said to be projected and which in consequence is called the *plane of projection*, has a real objective existence. It is the plane or region of binocular attention, to which all visual images are referred in making judgments of relative distance or depth. If no other conditions than those of binocular projection determined the apparent distance of an object, the double images would always be seen in or near the plane of fixation. But kinaesthetic sensations from the ciliary muscle, the diffusion of the retinal images of objects nearer and farther than the point of fixation, and many other factors that are still to be considered, will cause the double images to be projected a greater or less distance than the object fixated. It will be discovered by the student that the doubled objects are rarely seen at the same distance as the single object upon which the eyes are converged, but usually nearer or farther away. They are, however, just as rarely seen at the actual distance of the object, appearing rather to be displaced toward the plane of fixation. This fact serves to prove that the reference of visual images to a plane of binocular fixation and attention is at least one of the several factors that conjointly determine the perception of distance.

Experiment XXVII. **The single perceptions of binocular vision.**

A. *The fusion of images from two similar objects.* Hold up the forefinger of each hand before the eyes, the two fingers being separated by a distance of four or five inches. Look between the fingers at the sky or wall beyond. Do you see four images, two of each finger?

Move the fingers toward one another until the two middle images combine. Does the middle image look more real than the shadowy images to the right and left?

By closing first one eye and then the other, determine to which

of the two eyes, respectively, belongs each of the two images that combine; each of the two that do not combine.

B. *The interocular distance.* Hold before the eyes a pair of dividers with the arms spread apart; look between the separated points at the sky, keeping them in such position that the points are on a level with and about four or five inches in front of the eyes. Gradually close the arms of the dividers, until two of the four images of the points unite. Measure this distance.

The distance measured in this way will usually be somewhat less than the *interocular distance*, *i.e.*, the distance between the centers of the two eyes. When the eyes are fixed upon the sky, the lines of sight are parallel, although there is often a slight convergence as for a nearer point. In dreamy reverie, the eyes are held as though gazing at something at an infinite distance and the lines of sight are nearly parallel. In all experiments requiring the parallel position of the two eyes, it is helpful to think of looking off into a very remote distance and to assume the mental attitude of reverie. When the eyes are held so that the lines of sight are parallel, the same distance separates the centers of the two pupils and the centers of the two retinae. A convenient method of measuring the interocular distance is to hold the eyes parallel and let some one measure with a rule the distance between the two pupils. The interocular distance must be found by actual measurement for each pair of eyes.

C. *Corresponding points.* Make in a card with the point of a pencil two holes at the interocular distance apart. Hold the card against the forehead with a hole exactly in front of each eye. Look through the two holes at some distant object. Do you appear to be looking through two holes or through only a single one? If the two holes do not appear as one, increase or diminish the distance between them on the card. A few trials may be necessary to find the proper distance to bring about perfect coincidence.

Corresponding points are the two points, one in each retina, which habitually give rise either to a single visual image, as in the present experiment, or to superimposed but uncombined visual images, as in the cases to be illustrated under the next experiment. The visual images from corresponding points appear, therefore, to be projected to the same point in space, where they coincide and are seen as a single visual image, if the respective retinal images are alike, but are superimposed and seen as two uncombined visual images, if the retinal images on the corresponding points are unlike. To illustrate the relation of corresponding points to the fusion of the two similar images, let R and L in the accompanying diagram represent the retinae of the right and left eyes respectively. The cen-

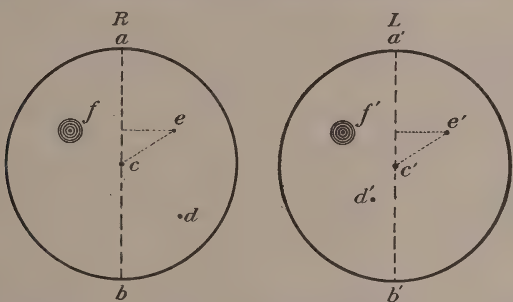


DIAGRAM XVI. Corresponding points and areas of the two retinae.

ters of the two retinae are indicated by c and c'. These are geometrically similar and anatomically identical points. They are also corresponding points, because the retinal images cast upon them by an external object usually give rise to a single visual image.

The lines $a\,c\,b$ and $a'\,c'\,b'$ divide the two retinae into bilaterally symmetrical halves. The right half of the retina of the right eye corresponds point for point with the right half of the left eye, and similarly the left half of the right eye corresponds with the left half of the left eye. Let e and e' be two

points geometrically similar and anatomically identical with reference to their distance and direction from the retinal centers c and c'. These are also likely to be corresponding points, that is, they will give rise to single vision. On the other hand, the two points d and d' are neither anatomically identical nor can they be physiologically corresponding points.

Identical points are usually, but not always, corresponding points. The two retinae seem to correspond for purposes of single vision, not point for point, but area for area. Thus a given small area of one retina represented by the concentric circles, f, is physiologically corresponding with an identical area in the other retina, f', also represented by concentric circles. When the central points of these areas are stimulated, single vision always results; when the center of one area and any other point of the identical area are stimulated, single or double vision may result; when the center of one area and a point outside the identical area are stimulated, double vision always results.

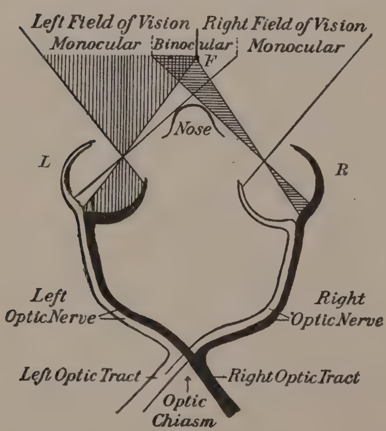


Diagram XVII. The fibres of the optic nerves from homonomous halves of the two retinae unite at the chiasm to constitute the optic tracts.

The anatomical basis for the fusion of visual images from the right and left halves of the retinae is represented in Diagram XVII. The eyes are supposed to be directed upon the point F. The external field of vision is divided at the point of fixation, F, into a left field of vision and a right field. The portion of the left field of vision affecting the right eye is represented by horizontal lines; an object in this part of the field of vision acts upon the right half of the retina. This

portion of the left field of vision, *i.e.*, the left binocular field, and the rest of the left field, *i.e.*, the left monocular field, fall also upon the right half of the retina of the left eye. The binocular portion of the left field is common to the homonomous halves of the two retinae. It is from this part of the left external field that single binocular vision is possible. Each optic nerve as it emerges from the eye is composed of two groups of fibres. The group of fibres connected with the right half of each retina is represented in the diagram by a heavy black line. These fibres constitute about one-half of each optic nerve until they reach the optic chiasm. Here those from the left eye cross and join the corresponding fibres from the right eye; together they then constitute the right optic tract which is in physiological connection with the right half of the brain. The fibres from the left half of the retina of the right eye also cross in the chiasm and join those from the left half of the left eye to compose the left optic tract, which is similarly related to the left half of the brain. An injury causing destruction of the right optic tract will produce total blindness for objects contained within the left half of the field of vision, without affecting in any manner the vision for objects lying within the right half of the external field.

With the eyes fixed upon a point in space, how many other points can be seen single without changing the position of the two eyes? The geometrical figure that will be constructed by a combination of all the points seen singly at one moment of fixation is called the *horopter*. On the supposition that the retina is the inner surface of a perfect sphere, and that all the points casting images upon identical points will be seen single, the horopter will be the inner surface of a large sphere passing through the point of fixation and the centers of the two eyes. By definition, every point that is not in the surface of this sphere will give rise to double images. The horopter, as a matter of fact, is a much more complex figure, because:

(1) the eye-globes are not perfect spheres; (2) anatomically identical points do not always give single vision; (3) those points which do give single vision, called *corresponding points*, seem to have a different relative location in the retinae for different positions of the two eyes.

D. *The line of binocular sight.*

1. Observe that when the two holes in the card are binocularly combined, the single hole is seen at a middle point between the two eyes.

2. Rule on a sheet of paper two parallel lines, five or six inches long, at the interocular distance apart. Cut a notch in the end of the sheet, midway between the two parallel lines, so that it will fit against the root of the nose. Hold the sheet in such position against the nose that you are able to look along its upper surface with the lines ruled upon it. Look at some distant object to get the two eyes in the parallel position. Each eye will then be directed along a line that extends straight out from it. Do the two lines now combine into a single line apparently extending outward from the root of the nose?

3. Hold a card vertically against the nose and forehead. When you look at a distant object, do you seem to be looking between two shadowy cards at the interocular distance apart?

4. In a sheet of paper, of foolscap size, make a small hole with the point of a pencil. Hold the paper close to the eyes, with the hole to the right of the right eye and on a level with it. Hold the two eyes parallel, as though looking beyond the paper at the wall or sky. Move the sheet toward the left so that the hole passes directly first in front of the right eye and then in front of the left eye. The hole will appear at the right of the median line, move across the median line and disappear to the left, to be followed a moment later by a second hole running the same course.

5. Look at the reflection of your eyes in a mirror. With the eyes in the parallel position, gradually approach the mirror until the nose and the forehead touch its surface. Do the eyes seem to combine into one large eye?

Diagram XVIII represents the two eyes in the parallel position; the two holes in the sheet of paper or the two similar lines or objects are represented by A and B, which cast their images upon a and b, the centers of the right and left retinae respectively. When a single binocular perception results from the fusion of the two images, the apparent object is located somewhere along a median line drawn straight out between the two eyes from the root of the nose. The projection line of the right eye is apparently shifted in binocular vision half the inter-

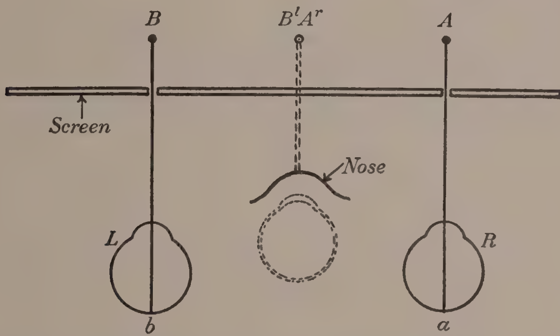


DIAGRAM XVIII. The shifting of the lines of monocular sight half the interocular distance to form a single line of binocular sight.

ocular distance to the left, and the projection line of the left eye half the interocular distance to the right. The superimposed and combined images, $B^l A^r$, will be seen as though they had been projected to some point along a common line of binocular projection. The lines of sight of the two eyes then appear to coincide in a single *line of binocular sight* extending, as represented in the diagram by the two broken lines, straight out from the root of the nose. The two eyes in binocular projection act together to give the same result that would be accomplished by a single eye situated at a mid-point between the two eyes. The two superimposed broken outlines of the right and left eyes suggest the relation of this imaginary

binocular eye to the line of binocular sight. The binocular eye is sometimes referred to as the "Cyclopean" eye.

An illusory appearance of such an eye is obtained in a striking fashion when a mirror is so adjusted to the two eyes that the reflection of the right eye is seen by that eye alone, and the reflection of the left eye by the left eye alone.

Experiment XXVIII. **Binocular "strife" from the superposition of dissimilar images.**

A. Hold up before the right eye the forefinger of the right hand, and before the left eye the palm of the left hand; look at the sky or wall between them. Do you observe the finger apparently lying in the palm of the hand?

Superimpose in the same way a finger and a pencil; pencils of different color; a pencil and a penholder.

Notice the curious alternation of the two images, first one and then the other being suppressed; sometimes both may seem to coexist for a moment in the same place.

B. Fix the gaze upon the squares of Chart 33, opposite page 92, holding the eyes parallel so as to look at the middle of the small white square with the right eye, and at the middle of the small black square with the left eye.

When the large and small black and white squares are superimposed, you will perceive now only the white design, now only the black; again the two will blend, not however to form a homogeneous gray, but in such a manner that black will be seen at some points and white at other points. This will give the effect of the "sheen" of a polished black surface, because such surfaces reflect, in addition to their own color, rays of white and colored light from surrounding objects.

It may be of assistance in this experiment and others of like nature to hold the chart against the forehead so that the figure to the right is opposite the right eye, and that to the left

opposite the left eye. With the chart in this position, get the eyes parallel by thinking of looking straight out through the chart into the distance. Move the chart slowly away from the head, keeping the distant view in mind so as not to disturb the parallelism of the eyes, but attending to the two designs while doing so. Repetition of this procedure is a great help in gaining control over the coördination of the eyes.

The shadowy images to the right and left of the superimposed images are often confusing and distracting. They may be prevented by the use of a screen. For combination with the eyes in the parallel position, a card three inches wide extending in the median line from the root of the nose to the designs or objects to be combined will entirely shut out the shadowy images. This is a median screen and obstructs the crossed ray lines from the objects to the retinae.

C. Superimpose the black and white squares by crossed fixation. Hold the head and the chart fixed, the chart being about fifteen inches before the face. The right eye must now be made to look directly at the small square to the left, and the left eye directly at the square to the right. To accomplish this, hold a pencil with the point uppermost between the eyes and the chart. Bring the pencil point into such position that, with the right eye closed, the left eye sees the pencil point in the middle of the square to the right; and with the left eye closed, but without moving the pencil or head or chart, the right eye sees the point in the middle of the square to the left.

To facilitate combination with the lines of sight crossed, two lateral screens are necessary, one directly in front of each eye, so that the direct rays are shut off and the crossed rays only are allowed to pass to the retinae. A very convenient form of lateral screen can be prepared by cutting out of the middle of a sheet of paper a circular opening about one inch in diameter. Hold this screen in a position between the eyes

and the objects to be combined, and move the screen toward and away from the eyes until the place is found at which, without moving the head or screen, the left eye can see through the circular opening only the object to the right, and the right eye can see only the object to the left. Then open both eyes and fix the gaze on the lower edge of the circular opening. Place a small plain cross on the screen at the edge of the opening to assist the eyes in converging steadily upon the plane of the screen.

Those who cannot combine these images binocularly, even with the aid of the screens, may find it necessary to prepare designs similar to the squares on Chart 33. Cut at the center of each design a hole one-eighth of an inch in diameter, and paste the two designs on a piece of window glass with their centers at the interocular distance apart. Hold the glass against the eyes, looking through the central openings at the sky; move the glass away until it is about a foot distant, keeping the eyes in the same fixed parallel position. The eyes will then easily retain the requisite parallel coördination.

D. Take a sheet of note paper and roll it into a tube about three-quarters of an inch in diameter. With the left eye, look through the tube at the objects beyond. Hold the back of the right hand four inches distant from, and directly in front of, the right eye. Look at the hand and through the tube at the same time. Do you seem to be looking through a hole in the hand? Do you see the skin of the hand across the apparent hole? Make a mark with red or black ink upon the part of the hand which disappears in the hole. Are you able to see the mark in the hole? Do you now notice a hazy outline of the skin of the hand extending across the hole?

E. Superimpose the images of the apple and the plate (Chart 38, opposite page 144), holding the eyes so that the lines of sight are either (*a*) parallel or (*b*) crossed. When the image of the apple is imposed upon the image of the defective middle portion of

the plate, do the two images appear to combine into the single perception of an apple on a plate?

In cases of binocular strife, the image that has distinctive features likely to gain attention will be perceived while the less attractive image may be totally suppressed.

Experiment XXIX. **The perception of reality and solidity from the binocular fusion of similar images.**

A. Place two small coins at about the interocular distance apart, projecting over the edge of the table, with the same side up and in similar positions. Look at the right-hand coin with the right eye and at the left-hand coin with the left eye. In order to do this, imagine yourself looking beyond the coins at the floor, or at some object at a still greater distance. Do you see an apparently solid and real coin halfway between two shadowy coins?

Hold a card extending from the root of the nose and forehead to the table midway between the two coins. Do the shadowy images disappear, leaving the single coin in the middle looking still more real than before?

B. Combine the crossed images of the coins as directed under Experiment XXVIII, C, page 139. Without the screen, there will be seen an apparently solid and real coin and two shadowy images on each side of it; with the screen, the combined coin remains and the shadowy images are shut off.

Diagram XIX represents the eyes binocularly adjusted to the point *F*. Nearer than this point are two objects represented by a cross and a circle. When the cross and the circle are exactly on the ray lines of the point binocularly fixated, the cross casts its image upon the fovea centralis of the right eye, and the circle casts its image upon the fovea centralis of the left eye. If the images are from similar objects, for example, the two coins, they will fuse into the image of an apparently single and solid object. A screen extending outward from the

root of the nose will cut off the heteronomous images. This screen is represented obstructing the ray lines from the cross to the left eye and from the circle to the right eye.

The right eye's image of the cross is projected along the line extending from the fovea centralis of the right eye to the point of fixation, F; the left eye's image of the circle is projected along the line extending from the fovea centralis of the left eye, also to the point of fixation. The diagram represents the two images superimposed or combined, as the case may be, at the point of fixation where the two lines of projection intersect. This point of intersection does not, however, determine the distance at which the combined image will be seen, but only its direction. The object will appear to be somewhere along the line of binocular sight, which extends from the root of the nose to the point F. The distance of the combined image will be approximately the distance of the two objects producing the monocular images. The direction of the binocular image is determined by the point of intersection of the monocular lines of projection. The locality of the point of intersection is determined by the amount of convergence of the two eyes necessary for binocular adjustment to the distance of the point of fixation. The distance of the binocular image is dependent to some extent upon the amount of convergence also, but it is chiefly determined by other and more general conditions of space-perception already given consideration in this chapter.

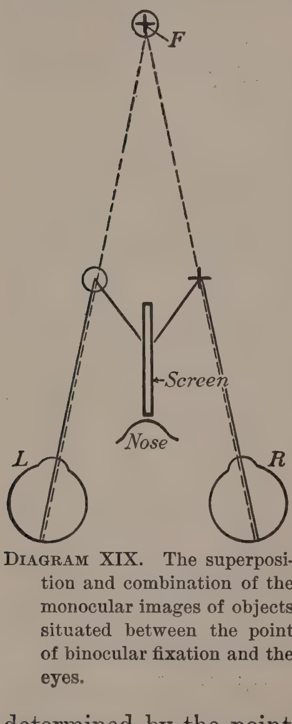


DIAGRAM XIX. The superposition and combination of the monocular images of objects situated between the point of binocular fixation and the eyes.

If the point of fixation is nearer than the two objects which are to be binocularly combined (see Diagram XX), a double screen, one for each eye, or a single screen with a central opening, must be employed. The point of fixation represented in the diagram is in the opening of the screen; the cross casts its image upon the center of the retina of the right eye, and the circle casts its image upon the center of the retina of the left eye; the projection lines of the two images intersect at the point of fixation. The ray line from the circle to the right eye, and the ray line from the cross to the left eye are obstructed by the screen; the formation of homonomous images is thereby prevented. If the superimposed images are from dissimilar objects, the result is binocular strife; if they are from similar objects, the result is the perception of an apparently single and real object.

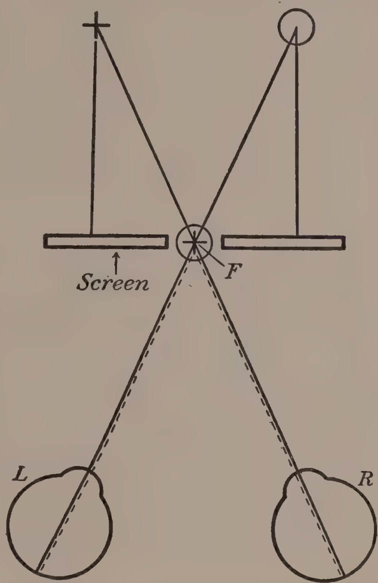


DIAGRAM XX. The superposition and combination of the monocular images of objects situated beyond the point of binocular fixation.

EXPERIMENT XXX. **Binocular perceptions of space.**

A. *The slightly dissimilar monocular images of an object of three dimensions.* Place a long thin book on the table with the back directed toward you, and at a distance of two or three feet; fixate the book with the two eyes. Close the left eye and draw the right eye's image of the book. Close the right eye and draw the

left eye's image of the book. Are the two images somewhat dissimilar?

B. *The successive combination of the monocular images of the parts of an object.* Hold a rod or a pencil horizontally before the eyes and pointing straight out from the root of the nose. Look at the farther end of the rod and observe the appearance of the rest of the rod. Fixate the nearer end and then the middle of the rod, observing the manner of doubling. Try with a thin long book, looking along the back. Can more than one point along the back of the book or the length of the rod be seen single at one time?

C. *The perception of a three-dimensional object, possessing apparent solidity and reality, from the binocular combination of flat or two-dimensional pictures and diagrams.*

1. Combine binocularly, from the parallel position of the lines of sight, the two views of the hall of a museum of art represented on Chart 38. Employ the median screen, if necessary, being careful that neither view is too much shaded by the screen. Combine binocularly the two views of the Italian peasants on the road to market. The combination of stereoscopic views with the naked eyes, without the assistance of the stereoscope, is accomplished by some with ease, but by others only with great difficulty. After the practice in binocular and monocular adjustment obtained from the preceding experiments, the student should combine without much trouble one or the other pair of stereoscopic views. After the lines of sight are nearly parallel, the right eye looking at the view to the right and the left eye at the one to the left, it is helpful to imagine oneself looking far off into the distant background of the scene.

The experiment with the rod and the book shows that when one part of an object is fixated, the parts that are nearer and farther away are seen double. When the nearer end of the rod or book is fixated, the double images appear $\vee$; when the farther end is fixated, they appear $\wedge$; when a median point is fixated, they appear $\times$. No object that has depth, *i.e.*, that

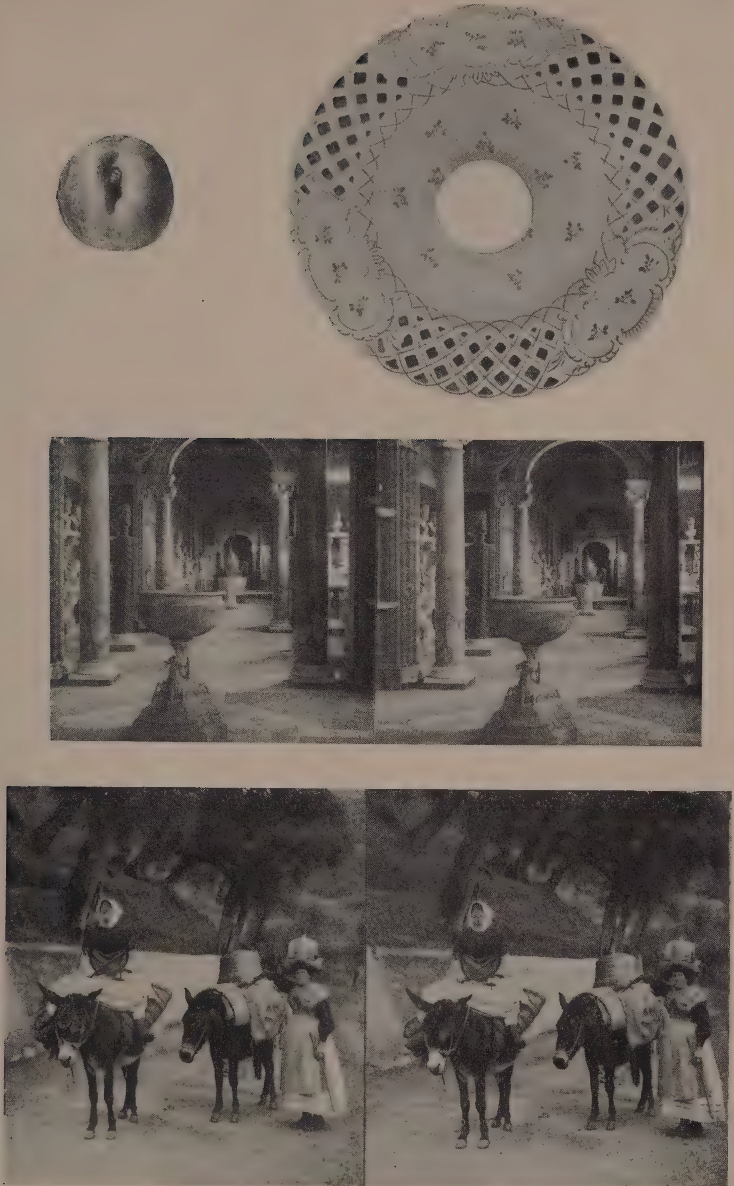


CHART 38

extends along a line straight out from the eyes, can be seen single in its entirety at any one time. It also appears from these experiments that the right eye's image of such an object is somewhat different from the left eye's image. The binocular perception of real objects extended in three dimensions requires, therefore, that the component parts of slightly dissimilar images be combined in rapid succession. The movements of attention and the eyes described in Chapter III, page 61, are those involved chiefly in the perception of two dimensions, *i.e.*, movements to the right and left and up and down over such parts of an object as are at the same distance from the eyes. The perception of the third dimension involves the eye movements necessary for converging the lines of sight successively upon the several parts of the object that are at different distances from the eyes.

The flat or two-dimensional views of the interior of the museum of art are slightly dissimilar. The distance separating the two pictures of an object in the background is greater than that separating those of an object in the foreground. When the views are binocularly combined from the parallel position of the lines of sight, the eyes must be somewhat more converged to get a single image of the font in the foreground than to get a single image of the urn in the background. All the objects represented cannot be made single at one time. Careful observation may show that when an object in the foreground is single an object in the background gives overlapping double images. Slight movements of the eyes laterally over the surface of the views, bringing different objects into the center of most distinct vision, will be accompanied by changes in the amount of convergence necessary to make the images of the different objects single as well as distinct. As soon as the eyes are properly adjusted and the two views are being combined point for point in rapid succession, the flat pictures are transformed into a single and very realistic view of the scene;

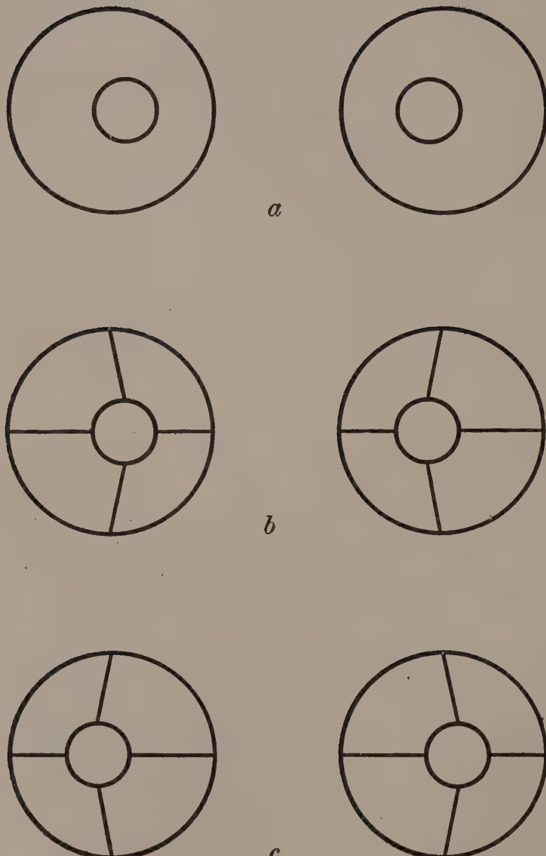


CHART 39

the illusion of gazing upon the actual objects portrayed in the pictures is often remarkably strong. The movements of the eyes are then very similar to those that would be produced were we looking at the three-dimensional objects of the scene represented, and not at their flat or two-dimensional pictures. The perception that results from the binocular combination of these pictures has a greater semblance of reality than the perception that results from directing the eyes to a single one of the two views.

The stereoscope is an instrument that facilitates binocular combination, assisting the eyes to assume the requisite convergence and increasing the definition of the retinal images. The two pairs of slightly dissimilar views on Chart 38 are made from photographs prepared for use with a stereoscope. The reality and life-likeness of photographs combined, either with the stereoscope or with the naked eyes, are readily observed by most persons. Some, however, appear to get no more from stereoscopic photographs than from a flat picture. They see the picture but do not apperceive the scene represented, as one unfamiliar with the English language may distinguish the letters of this page and yet fail to apprehend the thought intended to be conveyed by the words.

2. Combine with the lines of sight, either parallel or crossed, the circles of Chart 39, *a*. Is it possible to combine at one time in a single perception both the larger and the smaller circles? Or is there an overlapping of the one pair of circles when the other is single? Does the combined smaller circle appear to be in the same plane, *i.e.*, at the same distance, as the combined larger circle?

The centers of the two smaller circles are nearer together than the centers of the two larger circles. It therefore requires greater convergence from the parallel position to combine the

smaller circles than to combine the larger circles. The combined image of the smaller circles will in consequence appear to be nearer than the combined image of the larger circles. This may give rise to the perception of a funnel or truncated cone, the smaller end of which is directed toward the eyes.

If the circles are combined with the lines of sight crossed, the smaller circles combine with less convergence than the larger circles, and, when combined, the smaller circle will appear to be farther away than the larger circle. If the perception of a solid object results from such combination, you will seem to be looking into the interior of a funnel, the small end of which is directed away from you.

3. Combine the two figures of Chart 39, *b*.

The lines drawn from the smaller to the larger circles should increase the apparent reality of the perception resulting from binocular combination. If the eyes are steadily fixed upon the smaller circles, the images of the smaller circles exactly coincide, while the larger circles overlap and the straight lines connecting the two circles are also doubled. Many persons will be unable to observe the doubling of points not fixated, because the eyes change their convergence so rapidly that as soon as any one part of the diagram is given the least attention, the binocular adaptation for this part follows, and the part instantly becomes single. When these figures are binocularly combined, they cause a successive fusion of the component parts of dissimilar images and thus realize the conditions that are produced when an actual funnel is viewed with the two eyes.

4. Combine the two figures of Chart 39, *c*.

In *c* of Chart 40 the centers of the smaller circles are farther apart than the centers of the larger circles. When these figures are combined from the parallel position, the small circles require

for their combination a less amount of convergence than the large circles. In consequence, their coinciding images combine in a plane more distant than the plane of combination of the larger circles. From the parallel position, the combined image is the perception of the inside of a funnel, the small end of which is directed away. Crossed combination produces the opposite perception of a funnel seen from the outside, the smaller end being directed toward the eyes.

Experiment XXXI. **The advantage of binocular over monocular vision.**

A. Mark a spot on a sheet of paper with a pencil point. Place on the table before a subject, and require him to touch the spot with the point of a pencil held in the right hand. Make ten trials with (*a*) both eyes, (*b*) the right eye, (*c*) the left eye. Use a different spot for *a*, *b*, and *c*, and change the position of the paper somewhat after each trial. Let the subject drop his hand to his side after each trial, and endeavor to touch the spot with a single movement. The distance of the mark made by the subject from the given spot will measure the subject's error. Obtain the average error for each of the three series of ten trials. Compare by means of the three average results the relative accuracy with both eyes and with the right or left eye alone.

The errors made are composed of an error of vision and an error of coördination in the movement of the right hand toward the spot located by vision. The latter error remains constant throughout the three series; differences in the average errors, therefore, indicate the relative accuracy of vision with both eyes and with each eye alone.

B. The error due to the arm movement is eliminated by the Hering binocular test, which permits of the comparison of an unknown nearer or farther distance with a constant distance. The

apparatus consists of a partial screen for the two eyes, through which the subject looks straight ahead at a black ball suspended upon a thread at the distance of about twelve inches from the eyes. Let the experimenter drop the white balls provided with the apparatus nearer or farther from the eyes than the ball fixated. The white ball must be dropped from a position at which it cannot be seen by the subject, and allowed to fall to the right or left of the black ball in order that his judgment may not be assisted by the intercepting images. As each ball is about to be dropped, let the experimenter say "Now" as a signal to the subject to fixate the black ball and to prepare to give a judgment on the relative distance of the falling white ball. Make ten trials with the white ball nearer, and ten trials with the white ball farther, than the black ball, with (*a*) both eyes; (*b*) the right eye; (*c*) the left eye. Record the number of errors and compare the relative accuracy of binocular and monocular vision.

C. A substitute for the Hering binocular apparatus can easily be prepared by rolling a sheet of cardboard into a tube five inches in diameter and twenty inches long, tying the roll together at the ends with string, or binding in any other convenient fashion. At a distance of about fourteen inches from one end of the tube, pass a black thread across the diameter of the tube. The roll can then be held up before the eyes of the subject and the thread fixated so that it is seen stretched horizontally across the tube through which the subject is looking. Above and below, cut out two slits, about two inches wide, and extending longitudinally for a distance of ten inches. The slits ought to extend equal distances in both directions from the thread. The white ball (a bullet, marble, or any small round object) may be dropped from above through the upper and lower slits, passing in front of or beyond the thread, and caught in the hand below or allowed to fall upon some soft material on the table to deaden the sound. A shoe button or bead may be strung on the thread to serve as the object of fixation, but this is not essential, as the subject may compare the relative distances of the falling object and the bare thread. Instead of the tube of cardboard here suggested, a long, narrow paper box will

serve the purpose if the two ends are removed, a thread strung across the narrow section of the box, and slits cut in the top and bottom.

To see an object and to locate it accurately in the space external to the body would seem to be a very simple matter until the conditions that determine the formation of visual perceptions are subjected to analysis. The experiments of this chapter have shown that these conditions are exceedingly complicated. And yet only the more important features of the "space" problem have been considered. It would carry us too far afield in psychological speculation if we should endeavor to state and answer all the questions that present themselves during the course of an examination of our perceptions of space. The facts and general principles of visual space perception, illustrated and discussed under the several experiments of this chapter, may be briefly stated in a concluding summary.

1. The sensations due to the retinal image serve as the mental cue to which apperception responds with a complete space perception. Important elements of the experience which has formed apperception are: (*a*) the fact that the nearer of two objects may hide from view parts of the farther object; (*b*) the diminution in the size and clearness of the visual image as the distance of the object from the eyes becomes greater; and (*c*) the comparison of the object as otherwise known with its visual image and with the perception of other objects whose size is also known. This knowledge has been gained from visual perceptions with one eye and both eyes in many different positions, and from perceptions received through other senses than that of vision.

2. Although the object is never seen single in its entirety at any one moment of perception, it appears single because selective attention emphasizes the unity of the object and, in cases of double perception, may suppress one of the two images. This

is so marked that many persons fail to observe, until attention is called to them, the double perceptions which are received from nearly all other points than the one fixated.

3. The single complete perception is not dependent on the visual images of the moment. It represents a fusion of successive mental contents, each one determined by the eye movements of convergence and direction necessary to bring the points of the object successively to single and clear perception. The perception of an object may be likened to a composite photograph which gives emphasis to the components that have been most pronounced and constant in the different pictures superimposed.

4. A "space perception" is an association of many different mental contents, among which kinaesthetic sensations are the most important. The eye movements of convergence and direction, and the contraction of the ciliary muscle, give rise to associated kinaesthetic sensations which are interpreted in perception as definite location and distance.

5. The rapid changes in convergence which are necessary to give rise successively to the single perception of the several parts of an object are accomplished automatically. With one point fixated, farther points have been shown to be homonomously doubled and nearer points to be heteronomously doubled. This difference in the visual images of nearer and farther points suffices to originate the altered contraction of the muscles of the eye necessary to increase or decrease the amount of convergence as may be required to bring a nearer or a farther point to singleness of perception. At the close of Chapter II, in considering the direction of the lines of sight of the two eyes upon an object that is casting its images on the lateral portions of the retinae, a distinction was made between automatic movements accompanied by consciousness and automatic movements without consciousness. The two eyes constitute a single complex mechanism for the adjustment of convergence as well

as for that of direction. As in the case of the direction of the lines of sight, so also with respect to convergence, it is often impossible in a given instance to ascertain whether consciousness has been a necessary factor in determining the physiological adjustment. It can, however, be demonstrated that in some cases these movements take place automatically and without consciousness, but in other cases are controlled by consciousness and volition.

6. The character, size, and relative clearness of the retinal image also contribute to the spacial perception of objects localized in the field of vision. Those mental elements of the perception which are due solely to the retinal image are most appropriately designated *retinal* sensations. The sensations attributed to the eye, under the name of *visual* sensations, are in reality composed of both retinal and associated kinaesthetic sensations. Even the simplest retinal sensations, for example those of color, are experienced only as the component parts of complexer perceptions. If we could have the retinal sensation "red" existing alone in consciousness, it would be necessary for us to experience redness without apparent size and location. A sensation, psychologically considered, is an abstraction of analysis. It is the simplest element which can be conceived of as forming a part of complexer contents. The chapters of the Manual to follow will consider the simpler aspects of the mental element of perception.

CHAPTER V

PSYCHO-PHYSIOLOGICAL ANALYSIS

Experiment XXXII. **Variations in the process of sensation.**

A. Procure two cards of the same size, *e.g.*, visiting cards. Notch an edge of each card so that the two notched edges present a saw-toothed appearance. Apply the two notched edges to the skin of the forearm. Do the two edges seem of the same length? Cut from the notched edge of one card all but the two end teeth. Apply the notched edge and the edge with the two separated teeth to the forearm. Which seems the longer? Why?

B. Apply a pair of dividers or calipers (or a notched card) to the cheek with the points about three-quarters of an inch apart. Move them over the surface of the cheek toward the mouth so that one point traverses the surface of the upper lip and the other that of the lower. Does the distance between the points seem to increase as they are moved from the cheek toward the lips?

C. Get a straw or slender strip of wood about six inches long. Paste two squares, or circles, of white paper and of the same size, one to each end of the straw. Grasp the straw in the middle with the thumb and forefinger of the right hand and hold up before the right eye. Close the left eye and look at the two white squares so that the one to the left is in the center of the field of vision, and the one to the right is off to one side. Does the one seen in indirect vision seem larger than the one seen in direct vision? If you move the straw about, does the square seen in indirect vision appear to move more rapidly?

These perceptions of variable size are determined under conditions excluding other sources of variation than the respective touch and visual sensations; they serve to demonstrate the dependence of space perceptions upon the process of sensation.

EXPERIMENT XXXIII. **Local variations in the quality and intensity of sensation.**

A. *Sensations of heat and cold.* Hold a piece of ice in the palm of the hand, on the back of the hand, against the forehead, the cheek, and in the mouth. Does the intensity of the cold and the pain vary in the different localities? Touch with a piece of heated metal the finger tip, the palm and back of the hand, the forehead, the lips, and the tongue. Place the entire hand in iced water; do you get a more intense sensation of cold from the palm or back of the hand?

B. *The sensation of pain.* With the Cattell pressure algometer determine the least amount of pressure producing pain on: (*a*) the ball of the thumb of the right hand; (*b*) the ball of the thumb of the left hand; (*c*) the middle line of the forehead; (*d*) the forehead to the right of the middle line; (*e*) the crown of the head. Apply the algometer, increasing the pressure gradually until the subject notices that the pressure is just becoming painful. Record the minimum pressure for each locality in kilograms as read upon the scale of the instrument. Make five measurements in each locality and get average results.

C. *Sensations of color — the color fields.* Let the subject fixate with one eye a point marked upon the blackboard or a large sheet of white or medium gray paper fastened against the wall. The eye should be only a few inches distant from the mark fixated. Draw intersecting vertical and horizontal lines through the point of fixation. Cut out a square, a half-inch on a side, from a standard red, yellow, green, blue, black, and white paper (*e.g.*, Charts 9–14). Attach each square to the end of a pencil or straw. Hold one of the four colored squares considerably to the right of the point fixated, and then move it slowly along the horizontal line toward the point of fixation. Let the subject announce as soon as he sees something. As the paper is moved inward let him continue repeatedly to announce the color that he thinks he sees (some colors appear to undergo characteristic changes as they approach the center of the field), until the point is reached at which he is absolutely certain of the color. Mark on the horizontal line the

point at which the subject first recognizes the color employed. Make two trials with each of the four colors, and, as a check experiment, use the black and the white squares. Which of the four colors can be seen farthest from the point of fixation? What is the order of visibility of the colors from the center of the field outward?

Determine by a similar procedure the farthest points at which each color can be discriminated along the horizontal line to the left, and along the vertical line above and below the point of

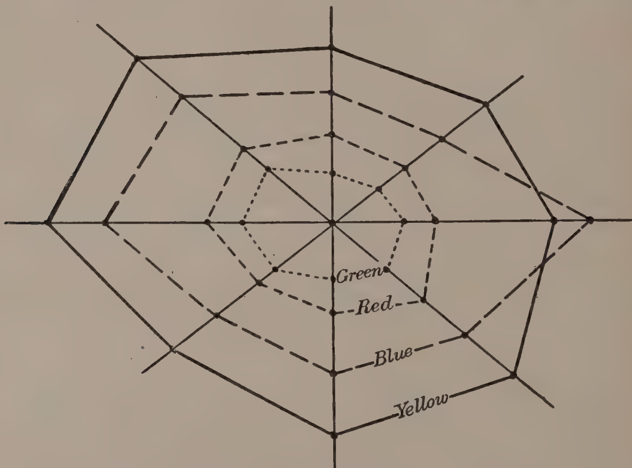


DIAGRAM XXI. The color fields of the left eye.

fixation. Is the order of visibility the same in the four linear directions from the center of the field? Care must be had that the eye is not moved; all results should be discarded in which a movement of the eyes has taken place or been suspected.

Between the two points found for each color in each direction from the center, mark a median point; connect the four median points of each color by a line, drawing each color line with a crayon or pencil of the corresponding color.

The field of color perception is less extensive than the field of vision (pages 50–52). The accompanying diagram represents

the *color fields* of the left eye, determined by the method of this experiment, excepting that the extreme points of color vision were ascertained along oblique lines as well as along the horizontal and vertical lines. An object in the external field of vision, colored in red, green, yellow, and blue, can be perceived in all its actual variety of color, only when it lies within the area or part of the external field bounded by the smallest line, the one marked "Green." If the object lies beyond the area circumscribed by the line marked "Red," neither the red nor the green of such an object will produce the corresponding color sensations; these colors will appear as shades of gray. If such an object lies beyond the outermost line marked "Yellow," its yellow and blue coloration will also fail to produce sensations of these respective colors, and the object will appear uncolored. The field of gray, or of white and black, is coterminous with the field of monocular vision.

These external areas of the field of vision correspond to sensitive areas of the retina. The color fields plotted by careful experimentation are not usually so regular in outline as those represented in the diagram above; they vary in extent with the size of the colored object, with the intensity of illumination, and with other conditions. The fact remains, however, that the retinal limits for red-green vision are more restricted than those for yellow-blue vision and that both these areas are less extensive than the area of sensitivity for black, white, or gray. It is inferred from this fact that the perception of color must be dependent upon retinal structures that are not uniformly distributed throughout the retina. The contrasting retinal sensations, red and green, yellow and blue, white and black, appear to be associated in pairs. This fact is accounted for on the supposition that there are three different retinal structures or elements, one of which is distributed throughout the entire sensitive area of the retina and when excited gives black and white, another less widely distributed giving yellow

and blue, and a third restricted to a relatively small central area giving red and green.

EXPERIMENT XXXIV. **The distribution of areas of different sense qualities over the skin.**

A. *The differentiation of heat and cold spots.*

1. Move the cool point of a lead pencil slowly and gently over the skin on the back of the hand or over the inner surface of the forearm. Do you notice that the cold sensation is distinct only on certain spots of the skin?

2. Heat the pencil point and test in the same way for heat spots. Which spots are the more easily detected, the heat or the cold spots?

B. *The exact location of heat and cold spots.*

1. Mark off on some part of the body, *e.g.*, the inner surface of the forearm, a twenty-millimetre (one-inch) square. Subdivide this square by cross-lines into 100 two-millimetre squares (64 one-eighth inch squares). Move the cool point of a pencil or blunt end of a needle over the skin through each of the small squares. Are you able to observe that the temperature sensations differ in quality in the different squares?

2. Perform the experiment, as above described, with the pencil point slightly heated.

3. Make a diagram of your results by marking within corresponding squares drawn on paper the location of the heat and cold spots found. Mark the heat spots with red ink and the cold spots with black. Use a hand magnifying glass for fixing the exact locality of a heat or cold spot.

C. *The location and qualitative differentiation of pressure spots.* Take a match stick sharpened to a point and test on an area of the forearm, marked as in B, for pressure spots, touching the sharpened end of the match stick upon spot after spot of the skin. What differences in pressure sensation do you detect when different spots are stimulated?

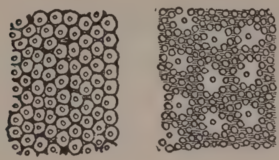
Every spot on the surface of the skin is not equally capable of giving rise to all the sensations that may be excited by the stimulation of the skin. The accompanying diagram represents an area about ten millimetres square on the skin at the base of the forearm in which have been located all the sense spots of heat, cold, and pressure, Figs. *a*, *b*, and *d*, respectively. These spots are referred for purposes of comparison to the distribution of the hairs in the same area, Fig. *c*. The distribution of the sense spots, as shown in the diagram, gives to the skin the appearance

DIAGRAM XXII. The distribution of (*a*) heat spots, (*b*) cold spots, (*c*) small hairs, and (*d*) pressure spots over the same small area (ten millimetres square) of the skin of the forearm, as determined by Goldscheider.

of a mosaic of diverse sensitive areas. If the cold spots alone could be removed from this area, sensations of heat and touch would arise from contact with a hot object, but only a sensation of touch from contact with a cold object; and yet, when a cold object is in contact with the skin, all portions of the skin touched seem to give rise to the cold sensation. There is no break in the sensations corresponding to the actual gaps in the sensitive areas.

A similar discontinuity of sensory surface is found in the retina also. The sensitivity of the retina is dependent upon the rods and cones. Fig. *a* of Diagram XXIII represents the distribution of the cones of the fovea centralis; Fig. *b* of the same diagram, the distribution of the rods and cones in a peripheral portion of the retina. Between the cones of the fovea centralis there are small interstices. In the lateral portions of the retina, the cones are more widely separated, and, although the rods are placed quite close together, forming a palisade, there are also non-sensitive spaces between them. A continuous blue surface acting upon the retina will stimulate discontinuous

sensitive rods and cones. The continuous sensation that results is to be attributed to the smallness of the interstices as compared with the sensitive points. It will be remembered in this connection that adjacent sensations are continued over even the large non-sensitive area of the blind spot. The half-tone reproductions of this book, Charts 28, 29, and 38, if examined closely, will be found to be made up of very small dots placed close together. At the distance of ordinary vision these dots give rise to a single continuous perception. The active portion of the retina's image is like a half-tone reproduction of the external object, whether this object be an aggregation of spots, as the illustrations referred to, or a continuous surface.



a *b*

DIAGRAM XXIII. The distribution of (*a*) the cones in the fovea centralis (the small circles are the cross-sections of the tops of the cones), and (*b*) the cones and rods in a lateral portion of the retina (the cones are the isolated circles, and the rods are the more numerous larger circles).

D. *The discrimination of small differences in sensations of touch — the so-called sensory circles.* Provide yourself with a pair of blunt calipers or compasses, and with a millimetre or foot rule. (An aesthesiometric compass prepared for the purpose may be obtained.) Touch the two points to the skin; be careful to apply them simultaneously; do not press upon the skin and avoid touching the hairs as much as possible. Require the subject to close his eyes and to announce whether he has been touched by two points or one. Make a preliminary experiment with the points close together, and another with the points quite far apart. When the points are close together, the subject will observe a single touch only; when they are very far apart, he will observe two.

Touch the skin with the points so far apart that the subject is quite certain that he has been touched by two points. Make a series of trials, bringing the points after each trial somewhat closer

together, until the subject makes an error by calling the two points one. Make another trial without decreasing the distance between the points. If the subject a second time judges the two points to be one, measure in millimetres the distance between the points and record this distance as the "just unnoticeable distance."

Make another series of trials, beginning this time with the points so close together that the subject is in no doubt as to the singleness of the sensation of touch received from them. Gradually increase the distance between the points until the subject in two successive trials correctly judges the two points as two. Record this distance as the "just noticeable distance."

In making the two series of experiments, touch the subject occasionally with but a single point, that he may never be certain whether he is actually touched with two points or but one. This is a "control" experiment; it compels the subject to rely entirely upon his sensations in giving his judgments.

Make five series of trials by each method of procedure, and calculate from them the average unnoticeable and the average noticeable distance. Average these two; this average result is the "threshold of sensory discrimination."

Determine the threshold in several selected regions of the body; for example, on (*a*) the outer surface of the left forearm, (*b*) the inner surface of the left forearm, (*c*) the back of the left hand, (*d*) the palm of the left hand, (*e*) the tip of the first finger of the left hand, (*f*) the forehead. Determine for each locality the threshold "lengthwise" and a separate threshold "crosswise" the selected part of the body. Do not make the five experiments of each set successively, but proceed from an experiment in one set to an experiment in another set, in this order: (1), just unnoticeable distance, lengthwise; (2), just noticeable distance, lengthwise; (3), just unnoticeable distance, crosswise; (4), just noticeable distance, crosswise. Calculate the average values. Do your results show discrimination to be better lengthwise than crosswise? Does the fineness of discrimination vary in different regions of the body?

When adjacent points of the skin are touched, the sensations of touch are very similar in quality. The points touched

must be separated by a certain distance, if they are to give rise to two sensations distinguishably different in quality. If one end of a pair of compasses is placed upon any point of the body and a circle of sufficient radius is drawn, all points within its circumference will give rise to a sensation not distinguishably different from that received from the point of the skin at the center of the circle. All points on the skin beyond the circle will give rise to sensations that are noticeably different in quality from the sensation received from the point at the center of the circle. The radius of this circle can be ascertained by the methods of this experiment. The sensory area included within the circumference of such a circle has been called a "sensory circle." The circle is drawn out in the direction of the long axis of the body or a limb, the area being strictly not circular but elliptical. The areas are more nearly circular early in life than later. This is probably due to the greater growth of the body and its members in the longitudinal than in the transverse direction.

The stimulation of the surface of the skin results in sensations of touch, pressure, heat, cold, and pain, depending upon the character of the stimulus and its mode of application. The stimulus acts either directly upon a nerve fibre or indirectly upon a sense organ connected with the nerve fibre. In either case the effect of the physical stimulation is a physiological excitation of the nerve fibre which is ultimately conducted to the outer surface, or *cortex*, of the cerebral hemispheres of the brain. A limited region of the cortex is the central cerebral center for the sensations of this group, other regions being the centers of taste, smell, hearing, and seeing, respectively. A stimulus cannot produce a sensation, unless it is conducted to its appropriate center. The nerve fibres are the processes or prolongations of nerve cells. A single nerve cell and connected fibre conduct the physiological excitation from a sense organ or from the free ending of the nerve to the spinal cord or base of

the brain. Other nerve cells with their fibre processes conduct the physiological excitation to the nerve cells in the respective center of the cortex. The physiological process of sensation involves, in most cases, a sense organ, several nerve cells and fibres of conduction, and the nerve cells of the cortical center. The various sensations received from the stimulation of the skin and deeper seated structures are qualitatively distinct from one another. Heat spots, cold spots, and perhaps also pressure spots can be distinguished and separated on the surface of the skin. It is natural to expect, in consequence, that there are different sense organs, nerve fibres of conduction and nerve cells in the cortex, for the several sensations of this group. The experimental evidence does not, however, positively establish the existence of different sense organs, nerve cells, and nerve fibres for each of the sensations of the group.

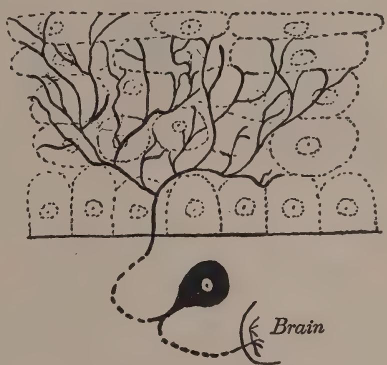


Diagram XXIV. The free ending of a nerve fibre among the structural cells of the skin.

The nerve cell represented in black in Diagram XXIV has its fibre terminating freely among the cells, outlined by the broken lines, which are the structural elements of the skin. The cell also sends a branch of its fibre toward the central nervous system, *i.e.*, the spinal cord or brain. In the pathway of conduction are other nerve cells and fibres, not shown in the diagram, which bring the physiological excitation to the cells of the cortical center. The physical stimulus acts directly upon the free endings of the nerve fibre.

A sense organ is composed of one or more specialized cells, in close connection with which the peripheral end of the nerve

fibre terminates. Fig. *b* of Diagram XXV is one of the simplest of these structures. It is an end bulb found in the conjunctiva of the eye, the mouth, and ligaments of the joints. The end bulb is composed of an outer wall forming an inner sack containing granular matter and nuclei. The nerve fibre may end within the bulb in various ways; in the one represented in the diagram, the two fibres enter the bulb and form a mesh of loops. Fig. *a* of Diagram XXV is a touch corpuscle found in the papillae of the skin, more especially in the palms of the hands and soles of the feet. As many as fifty have been counted in a square millimetre ($\frac{1}{25}$ of an inch) on the tip of the forefinger. Each corpuscle is composed of a large number of flattened cells; the cross-sections of these give the elliptical outlines seen in the figure. One or more fibres terminate in a spiral twist about the corpuscle. Fig. *c* represents another form of touch corpuscle found in the structures beneath the skin, near the joints and in the palmar surface of the hands and feet. Each corpuscle is built up of about fifty capsules concentrically arranged like the layers of an onion. The nerve fibre enters the corpuscle at one end and, cutting through all the capsules, terminates as a central stem or stalk. These structures are the simplest varieties of sense organs known. They are directly acted upon by the stimulus and in turn act upon the nerve fibre. Their function is to transform a physical stimulus into a physiological excitation, which is then conducted by nerve fibres to the brain. Their location protects them from excessive and destructive stimulation and from other stimuli than those for which they are specially adapted.

DIAGRAM XXV. Three simple varieties of sense organs in the skin and structures beneath.

EXPERIMENT XXXV. **The distribution of the sense organs of taste.**

Prepare solutions of (*a*) sugar, (*b*) quinine, (*c*) vinegar or acid, and (*d*) salt, of a strength that makes each solution just recognizable to the taste as sweet, bitter, acid, and salt, respectively. Dip a fine camel's-hair brush in one of the four solutions thus prepared. Let the subject open his mouth wide and thrust out the tongue as far as possible. Dry the tongue to prevent the solution from running and rinse out the mouth after each test. With the camel's-hair brush, touch individual fungiform papillae, the dark red spots upon the tongue; touch the large round circumvallate papillae arranged like a Λ near the back of the tongue; touch also the sides, tip, and root of the tongue. Try with all four solutions. Which parts of the tongue are most sensitive to each of the four tastable solutions? Do any papillae respond to only one of the four solutions, remaining quite insensible to the others? The experimenter may perform this experiment upon himself before a mirror.

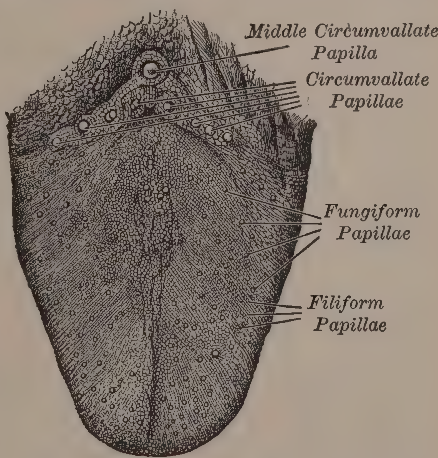


DIAGRAM XXVI. **The sensory papillae of the tongue.**

The three varieties of gustatory papillae seen on the surface of the tongue are shown in Diagram XXVI. These are the *circumvallate* papillae, arranged in the form of a Λ at the base of the tongue, the *fungiform* papillae, appearing as reddish spots, and the *filiform* papillae which give the furrowed appearance to the tongue. All of these may be easily recognized by examining the upper surface of the tongue in a mirror. The circumvallate papillae are circular pits, the

walls of which contain structures known as *taste buds*. These are spherical in shape and are composed of structural cells intermingled with specialized taste cells. The accompanying diagram represents a nerve fibre terminating in a taste bud. The structural cells are represented by the lighter outlines; two specialized taste cells are shown in heavy outline.

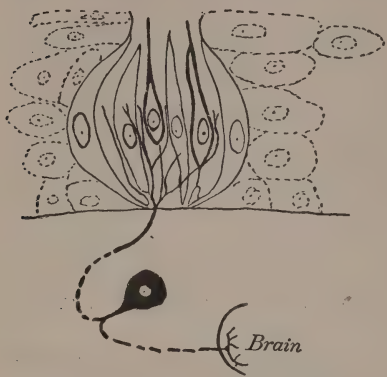


DIAGRAM XXVII. A nerve fibre of taste terminating about two taste cells of a taste bud.

Although the four different qualities of taste sensations, *i.e.*, sweet, salt, sour, and bitter, are not received each from all portions of the tongue, the tip giving sweet and not bitter, the root giving chiefly bitter, and despite the marked difference in the structure of papillae, it has not been possible to connect the four different taste qualities with any corresponding differences in the structure of the sense organs.

EXPERIMENT XXXVI. **The tone sensation.**

A. *Quality or pitch.* Strike in succession two or more tuning-forks or several keys of the piano. In what respect do these tones differ? What is the meaning of higher and lower? What is pitch? Is there a continuous series of tone sensations from the lowest possible tone to the highest?

B. *Intensity.* Hold a vibrating tuning-fork close to the ear and then at arm's length. In what respects does the sensation of tone vary under these conditions? Has every sensation of tone a distinctive quality and intensity? Strike a tuning-fork a sharp blow and let the sound gradually die away. Is there a continuous series of intensities from the loudest to the weakest tone?

C. *The sympathetic vibration of sounding bodies.* Place on the table two tuning-forks of the same pitch and one of different pitch. Strike one of the two similar forks vigorously. Stop the vibration of the fork that has been struck. Observe that the other fork of the same pitch is vibrating and gives rise to a tone sensation, whereas the third fork of different pitch is motionless and silent. When a note is struck on an instrument or sung near a piano, observe that some of the strings of the piano are thrown into vibration and others remain unmoved.

Touch the finger to a vibrating fork or to the vibrating string of a piano and observe that the vibrations give rise to a tingling sensation.

Sound sensations due to such vibrating bodies as a tuning-fork or the strings of a piano are called *tone sensations.* If we start with a tone sensation from any one string of the piano, we can, by striking adjacent strings, produce a series of tone sensations which will differ from the first either in *quality*, called *pitch* or in *intensity*. (For the consideration of quality, in the sense of timbre, see page 196.) All possible tone sensations may be arranged along a continuous line. This line graphically represents the fact that we may pass by small gradations from a tone of the lowest possible pitch to a tone of the highest possible pitch. If the strings of the piano were more numerous, we might pass from the lowest to the highest pitch by quite insensible gradations or changes in the quality of the tone sensations. Each tone sensation may also vary with respect to its intensity. If we represent the continuous qualities of tone sensation by a horizontal line, we may represent the variations in the intensity of each tone by a

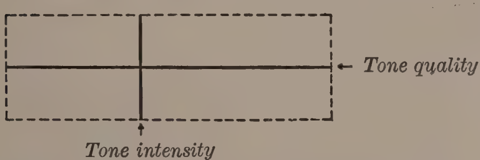


DIAGRAM XXVIII. The graphic representation of the continuity of tone qualities and intensities.

vertical line drawn from every point of the horizontal. The rectangular surface, Diagram XXVIII, will contain all possible variations of tone sensations, and graphically represents the fact that tone sensations constitute a continuous series of variable qualities and intensities.

The physical stimulus is a body vibrating a constant number of times per second. If the surface of the skin is touched once a second, a single touch sensation will result. If it is

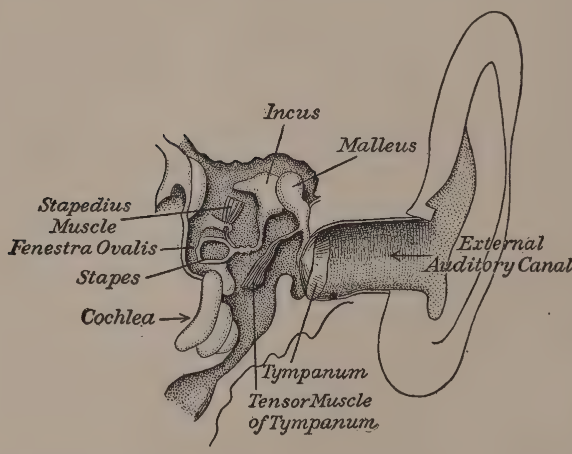


DIAGRAM XXIX. The conduction of the sound stimulus from the external auditory canal by means of the tympanum and the ear ossicles, the malleus, incus, and stapes to the internal ear, of which the cochlea alone is shown. The tensor muscle of the tympanum and stapedius muscle are supposed to adjust the tension of the tympanum and stapes respectively to the vibration rate of the auditory stimulus.

tapped two or three times a second, an equal number of rapidly intermittent touch sensations will be received. If the number of touches per second is greater than forty, each contact of the stimulus can no longer give rise to a distinct sensation; the mental result will be a sensation of tingling or roughness. The physiological processes, which are excited by the rapidly intermittent stimulations, are fused before they give rise to the

sensation. A sounding object strikes at constant intervals a mechanical blow upon the air adjacent to it. If these blows are as frequent as 8 per second and not more than 40,000 per second, they may produce a sensation of tone having a pitch determined by the number of impulses per second. The disturbance of the atmosphere is propagated from the layer of air adjacent to the source of vibration, by a wave motion, to the layer of air in the *external auditory canal* adjacent to the *tympanum* (see Diagram XXIX). This layer of the atmosphere will impart to the tympanum a series of rapidly intermittent shocks. From the tympanum of the *outer ear* the physical vibration is conducted across what is known as the *middle ear* by the three ear *ossicles*, the *malleus* or hammer, the *incus* or anvil, and the *stapes* or stirrup. The base or tread of the stirrup, projecting through the *fenestra ovalis*, an oval opening, communicates the vibration to the complex *inner ear*, known as the *labyrinth*. (See Diagram XXX.) The labyrinth is a bony cavity containing a membranous sac approximating the form of the cavity itself. The sac is surrounded by a liquid, called the *perilymph*, and is filled with a liquid called the *endolymph*. The middle portion of the labyrinth is called the *vestibule;* into this the base of the stapes projects through the oval window. The sense organ of tone sensation is the *cochlea*, a shell-like structure, situated at one end of the labyrinth and composed essentially of a canal, which winds two and a half times about the central axis. A vertical section of the cochlea is shown in Diagram XXXI. The winding canal is divided into two parts,

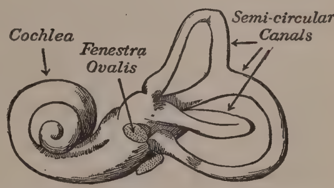


DIAGRAM XXX. The labyrinth or inner ear, showing the fenestra ovalis, into the middle part of which, called the vestibule, projects the base of the stapes; to the left is the cochlea, the organ of tone sensation, and to the right are the three semicircular canals, which are not supposed to be concerned in hearing, but constitute an organ of equilibration.

an upper and a lower, by a bony process, which extends from the central axis across the canal, but terminates before it reaches the outer wall. This bony process is shown in the lowest turn of the winding canal, extending part way from the central axis to the wall of the canal. The space between the bony process and the outer wall of the canal is spanned by

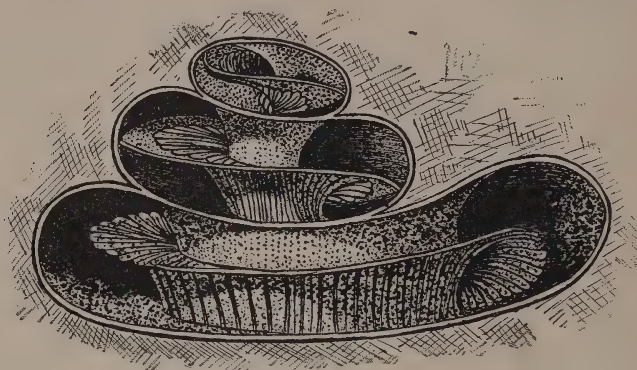


DIAGRAM XXXI. A vertical section of the cochlea.

several structures, of which we shall consider only those essential to hearing. The most important structure is the *basilar membrane*, which is shown in the middle turn of the winding canal in Diagram XXXI. The basilar membrane is composed of about 24,000 fibres, upon which are situated the *rods of Corti*, rising from the membrane and joining at their upper extremities to form a small tunnel over the membrane. Diagram XXXII represents a cross-section of the basilar membrane, with an outer and an inner rod forming an arch over the membrane. Close to the outer rods of Corti and external to them are four rows of hair cells, and internal to the inner rod is a single row of hair cells. These *hair cells* are in connection with the termination of the fibres of the auditory nerve. The fibres of the basilar membrane are supposed to be thrown into vibration by an external sound wave in the

same manner that one tuning-fork starts into sympathetic vibration a second fork of the same pitch. The membrane has therefore been called an inner piano. Some have thought that the rods of Corti also vibrated sympathetically in response to the external stimulus, but it is generally believed that their function is to dampen the vibration of the fibres upon which

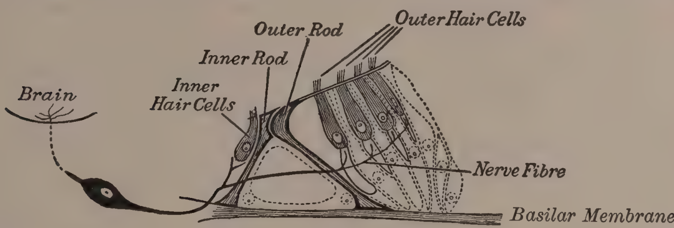


Diagram XXXII. The essential structures of the true sense organ of hearing. These are the four rows of outer hair cells and the single row of inner hair cells adjacent to the outer and inner rods of Corti, respectively, all of which structures are placed upon and supported by the basilar membrane, which is seen in cross-section below. The nerve fibre of hearing terminates at the base of and about the outer and inner hair cells. It is a process from a nerve cell, situated in the cochlea, and sending another process to terminate in the brain. From the central termination of the auditory nerve at the base of the brain, other nerve cells and fibres conduct the physiological excitation to the center of hearing in the cortex of the cerebral hemispheres.

they are placed. It is probable that the hair cells are also thrown into vibration by the liquid of the membranous labyrinth into which the hairs project. It can be said with certainty that the liquid, the rods, and the fibres of the basilar membrane are the structures one or all of which take up the physical sound vibration and in some mechanical way act upon the outer and inner hair cells. These cells are therefore the physiological organs, *i.e.*, the true sense organs of tone sensation, for when these are physiologically excited by the physical stimulus brought to them by way of the endolymph, the perilymph, the ear ossicles and the tympanum, they transform the physical stimulus into a nervous excitation by acting upon the terminals of the auditory nerve fibres. The sense of hearing is called a

mechanical sense because of this direct relation of the stimulus to the sense organ, namely, the hair cells. Practically nothing is known of the physiological processes that take place in the sensory cells. In consequence of this, the psycho-physiology of sound sensations is as yet of relatively small importance, whereas the psycho-physics of sound, which analyzes the relation of the sound sensation to the physical stimulus, has been greatly developed through the work of Helmholtz and others. The absence of any facts connecting tone sensations with definite physiological processes causes a further discussion of these sensations to be less appropriate in this chapter than in the chapter on the psycho-physical analysis of sensation.

Experiment XXXVII. **Retinal sensations.**

A. *The composite stimulus of the simple sensation of white.* Observe the color of a sheet of white paper in the sunlight. Hold in the sunlight, above the paper, a glass prism. Notice the rainbow spectrum thrown upon the paper.

If a sheet of paper appears to be white, it is because that particular piece of paper has the physical property of reflecting nearly all the *rays* of light, *i.e.*, the wave motions of ether, which fall upon it, very much as the banks of a river reflect or send back the wave motions of the water due to a passing steamboat. The medium corresponding to the water is the ether, which is supposed to fill all space. A source of illumination, the sun for example, sets the ether vibrating at different rates. Vibrations of about 450 million million per second give rise to the sensation of red; vibrations of 800 million million per second give rise to the sensation of violet; vibrations of intermediate frequency give rise to the intermediate color sensations of the spectrum; 526 million million vibrations per second give rise to the sensation of yellow, 589 to green,

640 to blue, and 790 to violet. If ether rays of all these rates of vibration act at the same time upon the retina, they will produce the simple sensation of white. There exist, also, vibrations of less frequency than 400 million million per second, which do not give rise to retinal sensations even though they may fall upon the retina. When they act upon the sur-

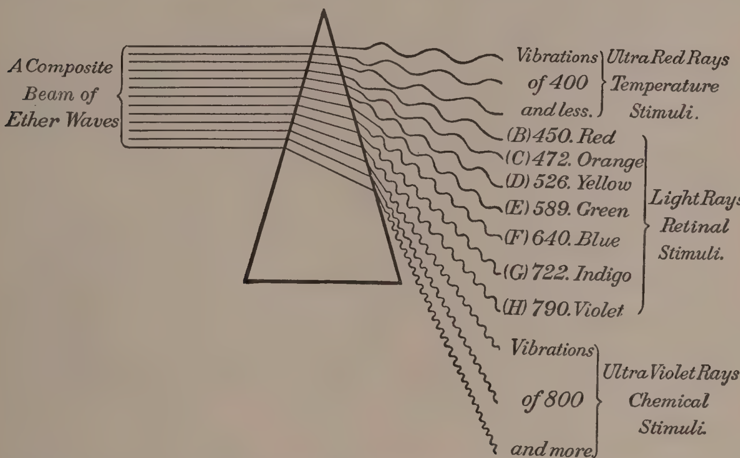


DIAGRAM XXXIII. The prism's analysis of a composite bundle of rays of different vibration frequencies. On the right is shown the relation of vibration frequency to temperature stimuli of heat and cold, to light stimuli of the various colors of the spectrum, and to chemical stimuli. The frequencies are in million millions per second, as given by Wundt. The letters B–H are the nearest lines of the solar spectrum to the vibration frequencies selected for the standard colors.

face of the body, they give rise to sensations of heat and cold respectively, depending upon their relation to the temperature of the part of the body stimulated. These vibrations are distinguished, as *heat rays*, from the vibrations which give rise to retinal sensations, which are known as *light rays*. Vibrations of greater frequency than 800 million million per second also produce no retinal sensations. They exert a chemical effect, if they act at all upon the various organs and tissues of the body,

and are known as chemical rays. The effect of light rays upon the rods and cones and pigment cells is also a chemical one. Vision has therefore been designated a chemical sense. The exact nature of this chemical action is not yet known. The physiological processes which are excited in the retina, so far as these are understood, will be considered shortly.

The prism separates the rays of different frequency of vibration. Diagram XXXIII represents a composite bundle or *beam* of rays directed upon the surface of a triangular prism. These rays are bent from their course or refracted by the prism, the amount of refraction being proportional to the rate of vibration. Rays of least frequency are refracted least, and those of greatest frequency most. When these rays are thus separated by the prism into a band of rays in which, as shown in the diagram, those of least frequency are at one end and those of greatest frequency at the other, with rays of intermediate frequency arranged in regular order between them, the light rays falling upon a sheet of white paper give rise to the characteristic band of spectral colors.

B. *The mixture of colored pigments and the fusion of the physiological processes in the retina.* Prepare three discs of white paper, by painting one of them with a blue pigment, another with a yellow pigment, and a third with an equal mixture of the two pigments. Have the discs of the same size and capable of adjustment to the color top or wheel. Place the yellow and blue discs together on the top, so that one-half of each disc shows. Spin the top rapidly and note the resultant sensation of color. Compare the sensation thus obtained from the yellow and the blue on the color top with that obtained from the two pigments physically mixed and painted upon the disc.

The apparatus suggested for use in this and the following experiments is the Bradley Color Top. This instrument, as shown in the diagram, consists of a spindle upon which can

be slipped a cardboard disc held in place by a wooden yoke fitting closely over the axis of the spindle. The top can easily be spun upon the table by giving it the proper twist with the fingers. Accompanying the top are paper discs of standard colors, somewhat smaller than the cardboard disc. Projecting beyond the edge of the colored discs, when these are fastened down with the yoke, are seen the ends of radii which divide the circumference of the cardboard disc into twenty parts, thus providing means for measuring the relative amount of each color exposed. Slit each disc from the circumference to the center and slip one over the other, in the manner represented in Diagram XXXV, until the desired amount of each color is exposed.

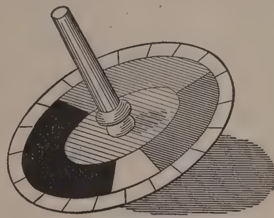


Diagram XXXIV. The color top.

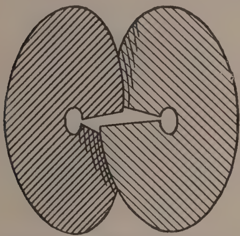


Diagram XXXV. The adjustment of the color discs.

The color wheel is more convenient for class-room demonstration, especially with small classes. This is a mechanical device for rotating color discs uniformly and at a very high rate of speed. The color discs, made of cardboard, are adjusted in precisely the same way as with the color top.

When yellow and blue pigments are mixed, they produce a green pigment. This is a physical mixture of colored substances. When yellow and blue discs are rotated rapidly on the color top, there is no physical mixture of the colors whatever. The rotation of the top causes each color to act in rapid succession upon the retina. Yellow and blue, when taken in proper proportion on the color top, give rise to a simple sensation of uncolored gray. Introspective analysis reveals in the sensation no trace of blue or yellow, nor yet of the green which resulted

from a mixture of the pigments. If neither the physical stimulus nor the sensation shows signs of mixture, the physiological processes of the brain, retina, or the connecting sensory nerves must be responsible for this want of correspondence between the sensation and its yellow and blue stimuli. The physiological fusion due to the rapidly intermittent action of the yellow and blue stimulus is generally supposed to take place in the retina. This experiment serves to illustrate the distinction that always must be drawn between the respective processes that are the subject-matter of psychology, physiology, and physics. The same name may be applied to very different objects. The word "color" may mean either the sensation or the physical object giving rise to the sensation. We must be careful to avoid inferring that conditions which are true of the stimulus are necessarily true of the sensation. A failure to regard the color sensation as distinct from the color stimulus has given red, yellow, and blue an unjustifiable preëminence. It is common to hear them spoken of as the three *primary* colors; because of this mistaken supposition, they are not infrequently taught in the schools before the other colors. For the purposes of painting, red, yellow, and blue are fundamental pigments, and green is a secondary color of composition, but for psychology, that is, for the mind, green is as much a primary color as are the others.

C. *The relation of retinal sensations to diminished illumination.* Hold two colored papers, one a blue and the other a shade of blue, squarely to the light. Keeping the shade of blue in the full light, gradually turn the blue away, thus diminishing the amount of its illumination. Can you find a slant of the blue, namely, a certain degree of darkness, where the blue can be made exactly to match the shade?

Try with a white and a gray paper, turning the white away from the light. Can you pass through insensible gradations from white to light gray, by diminishing the intensity of the illumination?

Do not all objects during the period of twilight gradually shade into black? May we not pass by insensible gradations from white to black by diminishing the illumination? Is black a sensation, or is it only the absence of white? Do not colors tend to blanch or become whitish under intense illumination? Would it not be possible to pass from black, or any color, to white by intensifying the illumination?

D. *The relation of color sensations to white and black.*

1. Use a color top or wheel. Take a red disc and a white one. Place them on a color top or wheel so that very little of the white shows. Observe the resultant color sensation, when the disc is whirled or the top is spun rapidly. Is it still a sensation of red?

Increase the amount of white that is allowed to show with the red. Observe the resultant color. Is it a whitish red — that is, a tint of red?

Gradually increase the amount of white until you get what appears to you a pure white. Can you reach pure white by passing through successively more whitish tints of red?

2. Use the red and a black disc. Can you pass from red to black by insensible gradations of shades of red?

3. Combine a blue, yellow, or green disc with white and with black discs. Do all colors tint into white and shade into black? Do you obtain a continuous series of insensible gradations from each color to white and to black?

4. Try with a white disc and a black one.

5. Combine a disc of any color with a gray one, or use, in place of the latter, black and white discs. Try several different colors and observe the result.

The stimulus of the white sensation is a bundle of rays of many different vibration frequencies, reflected generally from the surface of some external object. As the reflected rays diminish in number, the surface of the object becomes darker and by insensible gradations may pass through gray to black. A black surface reflects relatively few rays, but such as are reflected are of different vibration rates. The sensation of black

is not the absence of the sensation of white. Both are equally definite and equally simple retinal sensations. White and black, as sensations, are the opposite ends of a continuous series of grays. It is now common to refer to this continuous series of white-black or gray sensations as a *brightness* sensation. The difference between black and white is a difference of quality and not a difference of intensity. The color sensations red, yellow, green, and blue are composites of a color quality and the brightness quality. A sensation of color may have its brightness increased or diminished either by adding white or black respectively, or by increasing or diminishing the illumination. The less the admixture of the brightness quality, the more distinctive is the color quality; a color sensation with the least possible admixture of brightness is said to be *saturated*. It is common for us to speak of a more or less intense gray, and a more or less intense red, meaning thereby that the more intense gray and red are nearer to white, and the less intense gray and red are nearer to black. Because we have seen that this approach to black is generally obtained by diminishing the intensity of illumination, we wrongly infer that retinal sensations change in intensity also. This is another illustration of the application of a physical analogy to mental processes. Retinal sensations, unlike the tone sensation, do not possess intensity distinguishable from quality.

E. *Intermediate or mixed color sensations.* Mix on the color top varying proportions of red and yellow. Is the resulting sensation both red and yellow, *i.e.*, a mixture of the two, or is the sensation of orange as simple as are the sensations of red and yellow?

Mix on the color top varying proportions of red and blue, obtaining a series of sensations of purple intermediate between the red and blue. Is it possible to pass by insensible gradations from red to yellow, to green, to blue, and back again to red, passing through the intermediate variations of orange, yellow-green, green-blue,

violet, and purple? How many totally different sensations of color are there in this closed series? How would you determine the number of distinguishably different sensations?

The color qualities from red through yellow, green, and blue back to red may be represented on a continuous line. To indicate that these color qualities are an uninterrupted series, a circle may be chosen as the line of graphic representation. If white is represented by the center of the circle, radial lines from the circumference of the circle to the center will represent the graduated series of color tints from each color to white. To represent black, a point in space above the disc may be taken; lines from this point to the periphery of the circle will contain all shades of the spectral colors. A line drawn from the point that represents black to the center of the disc will contain the uncolored grays of the black-white series. In this way is developed the color cone, Diagram XXXVI, a figure within the continuous area of which are contained all possible retinal sensations. The apex of this cone stands for black, the central axis of the cone represents all variations from white to black through intermediate grays; around the periphery of the base are the spectral colors and purple; on the external curved surface of the cone are represented all possible combinations of these colors with black; the plane base of the cone contains all combinations of the spectral colors and white.

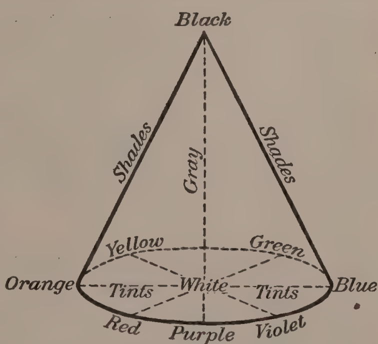


DIAGRAM XXXVI. The color cone.

The number of distinguishably different retinal sensations is very large. Titchener calculates that there are about thirty

thousand; according to other investigators, the number is much larger. The number of totally different color sensations is four — red, yellow, green, and blue. All other color sensations are combinations of these. Thus orange is readily perceived to be composed of red and yellow. It was quite unnecessary for Newton to distinguish and name seven colors of the spectrum, for the orange is clearly referable to the red and yellow, and the indigo and violet are scarcely distinguishable from blue. The number was chosen by Newton through a false analogy with the seven notes of the musical scale. He forced the analogy by distinguishing a greater number of colors than was necessary. In casting the eye over the spectrum, or in sorting colored worsteds and papers, the smallest number of colors that will make a satisfactory classification is four. These four colors may be called *principal* colors. Language bears evidence that the race has looked upon these as the distinctive colors. They were the first to receive special names. To designate variations of these colors, either composite names are used, as greenish-yellow, or the name of an object is taken, as orange and indigo-blue. In addition to these four specific color sensations are the sensations of black and white, constituting the opposite ends of the series of grays, and, in consequence, grouped together under the name of brightness sensation.

F. *The production of a sensation of uncolored gray by the combination of rays of color.*

1. Adjust on the color top a yellow and a blue disc in proportion to give a gray when the top is spun rapidly. Compare this with a gray obtained by combining black and white.
2. Combine red, green, and blue in proportions to give a gray.
3. Place on the color top discs of all the colors of the spectrum and find the proportions necessary to obtain a gray by composition.

Two colors that in combination give rise to an uncolored gray are called *complementary*. This gray is not distinguishable

as a sensation from the gray that results from a combination of black and white or of all the colors of the spectrum. The sensations that are produced by the multifarious colors of nature can be excited by red, green, blue-violet, and combinations of these. These colors, in consequence, have been called *primary* colors. Their significance as primary colors attaches only to the physiological processes of the retina, which are fused by the intermittent action of the stimuli on the top or wheel. For the purpose of developing color perception it is quite as mistaken to teach children in the schools that red, green, and blue are primary colors as it is to begin with the fundamental pigments of red, yellow, and green. The primary colors for the mind are the four principal colors — red, yellow, green, and blue.

G. *The sensitivity of the retina to color stimuli.*

1. Place before the subject a collection of worsteds or papers of all colors. Require him to sort according to the dominant color tone. Note any hesitation in sorting, especially in the handling of tints of red and green.

2. Use the color top or wheel. Place on the top a gray disc of medium intensity and a standard red disc, exposing only a very small portion of the red. Spin the top rapidly and ask the subject to observe the resultant color. He will probably judge the resultant sensation to be an uncolored gray. Increase very gradually the amount of red exposed until you find the amount that the subject is just capable of perceiving as a tingeing of the gray in the direction of red. The amount of red, *i.e.*, the sector of the disc exposed, is to be measured in terms of the degrees of the circle. Repeat this with a green, a yellow, and a blue disc, finding the different proportions that are just noticeable. Do not let the subject know which color is being mixed with the gray. In place of the gray disc, a white or a black one may be employed.

Different subjects will disclose considerable differences in the amount of a color that can be just discriminated when thus

mixed with gray. A few will be quite uncertain in their judgments, even with a large amount of the color disc exposed. They are probably color blind. The most common form of color blindness appears as a difficulty in discriminating red from green, and is frequently called red-green blindness. Less common forms are blue-violet blindness and blue-yellow blindness. Total color blindness also occurs, though rarely. In a group of twenty men or boys at least one should be found sufficiently insensitive to red or green to be called red-green blind. It is said that only one in a thousand women can be thus designated color blind. It is to be noted that the most common form of color blindness is an insensitivity to red or green; this corresponds with the smaller area of retinal sensitivity for these colors. (See pages 156–157.)

Color theories concern themselves with the physiological processes of the retina. These theories are for the most part inferences from the psycho-physical facts of color relationships, many of which have been presented in the course of these experiments. The Young-Helmholtz theory is based upon the results of color fusion in the retina. Red, green, and violet in different proportions will give rise to all possible color sensations. The theory assumes in consequence three different elements or processes in the retina, one for each of these so-called primary color sensations. The Hering theory is based upon the psychological significance of the six retinal sensations — red, yellow, green, blue, black, and white. Red and green are complementary and contrasting; so also are yellow and blue, and white and black. Red, yellow, and white are mentally distinguished as exciting colors, while green, blue, and black are considered quiet and restful. When an organ of the body is stimulated to perform its normal function, it tends through the continued exercise of that function to become exhausted. The chemical elements of which it is composed undergo a partial decomposition or dissimilation. The organ receives from the blood the

nutritive material through the assimilation of which its substance is renewed and the organ chemically reconstructed. The Hering theory assumes the existence of three elementary retinal substances: a red-green element, a yellow-blue element, and a white-black element. Red and green alone affect the red-green element; yellow and blue, the yellow-blue element; and white and black, the white-black element. The more exciting color stimuli, red, yellow, and white, produce a decomposition or dissimilation of the elements upon which they act; the less exciting stimuli, green, blue, and black, favor and assist organic assimilation and reconstruction. The physiological processes are therefore six in number, corresponding to the six principal elementary retinal sensations — red, green, yellow, blue, white, and black. All other sensations due to the action of light upon the retina are the mental result of a combination of these processes. Hering's theory, in one of the many modifications to which it has been subjected by psychologists and physiologists, is more generally accepted at the present day than the Young-Helmholtz theory.

Experiment XXXVIII. **Kinaesthetic sensations.**

Let some one move your arm or hand or one of your fingers. Do you notice that the sensations of movement differ from those which you receive from the member when it is at rest?

Voluntarily move the same member or members. Does the kinaesthetic sensation of an active movement differ from that of a passive movement?

Press a muscle with considerable force, for example the ball of the thumb. Do you notice a dull sensation that appears to have its origin in the muscle?

Attach a two or three pound weight by a string to the end of the middle finger; let the finger and attached weight hang down by your side. Do you notice a sensation of strain along the finger and arm? This sensation is due to the stretching of the tendons and

ligaments. With the eyes closed, lower the weight until it comes to rest upon some soft object placed to receive it. At the moment when the pull of the weight is removed, do you notice a push upward as though the string were rigid and had been thrust against the arm? Where is the push localized? This sensation of push is supposed to be due to the joints coming suddenly together after they have been slightly pulled apart by the weight.

Describe the kinaesthetic sensations accompanying the reflex movements of sneezing, coughing, and gaping.

The physiological source of the *kinaesthetic* sensation is partly in the muscles, partly in the joints, and partly in the tendons, ligaments, and even the skin. Sensations arising from the movements of the body are frequently called muscular sensations, and sometimes a "muscle sense" is spoken of. This terminology gives a false emphasis to the physiological contribution of the muscles. It would be more appropriate to speak of the joint sense, as the sense organs and nerves in the joints are of greater importance in giving rise to the kinaesthetic sensation than are those in the muscles. The physiological source, however, is in reality a composite one. It is doubtful whether introspective analysis is able to reveal a corresponding complexity of the sensation. As the sensation of white is a simple sensation due to a composition of colored rays, so the kinaesthetic sensation can be attributed to no single sense organ nor to any single stimulus, but must be regarded as the simple mental result of the several physiological processes in the muscles, joints, tendons, and skin. The fusion is, therefore, a physiological one, taking place before the distinctive kinaesthetic sensation has existence in consciousness.

Experiment XXXIX. **Sensations of rotation and dizziness.**

Spin about quickly on the feet for a number of seconds. When you stop, do you notice sensations of rotation and dizziness, and

some unsteadiness in walking or standing? Jerk the head with a voluntary movement to the right and left, up and down. Do you have the same unpleasant sensation of giddiness?

Sensations of rotation and dizziness are associated with the disturbance of bodily equilibrium. The maintenance of equilibrium is dependent upon physiological processes which have three different sources: (1) the muscles, skin, and other structures associated in bodily movement; (2) the eyes; and (3) the three semicircular canals (see Fig. XXX, page 169) situated at one end of the inner ear. At the bases of these canals are sensory cells connected with nerve fibres which constitute a branch of the auditory nerve. These cells and fibres seem to have no function in relation to hearing. A movement of the head disturbs the liquid of the labyrinth, *i.e.*, the endolymph, and this in turn excites the sensory cells. Disease of the semicircular canals produces disturbance of equilibrium, sensations of dizziness and nausea. The sensation of nausea is associated with the functions of the stomach, its particular source being the oesophagus. Sensations of rotation and dizziness cannot be ascribed to the semicircular canals alone; they are probably the mental result of a fusion of different physiological processes, some originating in the canals, but others, like the kinaesthetic sensation, in the structures usually excited by bodily movements, and still others in the internal organs, which are reflexly stimulated by an intense excitation of the sensory cells in the canals, conducted first to the brain and then by efferent nerves to the oesophagus and other internal organs.

Experiment XL. **The relation of sensation to the movements of the stimulus and sense organs.**

A. *Sensations from the stimulation of hairs.* Touch single hairs on the back of the hand or fingers. Do you notice that some

hairs are shaken and bent without any sensation being produced, while others enable you to feel the slightest movement, some without any tickling, and others with a decided tickle sensation?

B. *The sensation of tickle.* Tickle with a feather the skin of the palm of the left hand. Touch the same part with a single contact of the feather. Is the sensation of tickle qualitatively different from that of touch?

C. *The perception or sensation of motion on the surface of the skin.*

1. Let the subject close his eyes. Rest a pencil point gently on the subject's forearm over a spot marked with pencil or ink. Move the point slowly and evenly (*a*) up, (*b*) down the arm, (*c*) to the right, and (*d*) to the left. Make five experiments in each direction, choosing the direction of the movement at random. Require the subject to announce the fact of motion as soon as he perceives it. How far must the pencil point be moved before the subject feels its motion? Measure the distance in millimetres. Average the results.

2. Make twenty experiments, according to the directions given in C, 1, but this time requiring the subject to announce the direction of the motion as soon as he perceives it. How far must the pencil be moved from the marked spot before its direction is perceived? Measure the distance in millimetres. Average the results. Have the downward distances been greater than the upward? Those to the right greater than those to the left? If any erroneous judgments of direction are given, discard them and continue the experiment until the required number of correct judgments are obtained. Is movement perceived before its direction?

3. Compare these average values with the average distance at which two points can be just distinguished from one (Experiment XXXIV, D, page 160).

These experiments show that certain sensations are dependent upon the way in which the stimulus moves over the body rather than upon the stimulus itself. The tickle sensation, for example, is distinctive. It is not composed of an aggregation

of touch sensations. The stimulus, however, is an object moving lightly over the skin, producing a series of rapidly intermittent touches. The sensation of tickle cannot be related either to a specialized sense organ and nerve nor yet to any special stimulus. Its stimulus is a succession of intermittent touches acting upon the skin to stimulate the same nerves that mediate other sensations. The tickle sensation, like the sensation of white, would seem to result from a fusion of physiological processes.

The sensation of movement over the skin has probably a similar origin. Some psychologists, however, look upon the mental result of an object moving over the skin as a perception of movement, an inference from touch sensations changing rapidly in local quality. But the simple mental result of a movement over the skin is very different from that of a single touch. Moreover a movement over an exceedingly small stretch of surface will give rise to the movement sensation, whereas two touch stimuli separated by a much greater distance give rise to touch sensations that are alike in quality.

EXPERIMENT XLI. **The relation of sensation to general physiological conditions.**

A. *The amount of surface stimulated.*

1. Dip a finger in cold or hot water; then the whole hand. Which gives the more intense sensation, the finger or the hand?

2. Procure several boxes of different sizes. Load them with shot until they all have the same weight. Do not let the subject see or handle the boxes. Place them one after another on the palm of the subject's hand. What is the relation between the apparent weight and size?

B. *Physiological diffusion.* Compare the apparent size of the small white square on the black background with that of the small black square on the white background (Chart 33, opposite page 92).

A black surface absorbs nearly all the rays of light that fall upon it, reflecting very few rays to the retina. A white surface, on the other hand, reflects nearly all the rays falling upon it. The portions of the retina corresponding to the black surfaces in the figures are receiving relatively little stimulation, whereas adjacent areas of the retina are receiving a large amount of stimulation. The rays of light irradiate or spread into the non-stimulated areas and the physiological processes in the retina also tend to spread into adjoining areas. The small white square appears larger than a black square of the same size. The cause of this illusion is partly a physical irradiation of the rays of light and partly a physiological diffusion of the processes in the retina.

C. *The physiological zero point of temperature.*

1. Touch with your finger or hand (*a*) a piece of wood, (*b*) cloth, (*c*) metal, all being of the temperature of the room. Note the resulting sensations of temperature.

2. Take three vessels containing water: one at 20° C. (68° F.), the second at 30° C. (86° F.), and the third at 40° C. (104° F.). Put the forefinger of one hand into the warmest water, that of the other hand into the coldest. After one minute place both fingers in the water of medium temperature. Do the fingers give different temperature sensations?

3. Hold the hand for one minute in water of 10° C. (50° F.) and then transfer it to water of 20° C. (68° F.). Do you observe that the latter feels warm at first, but after a time cold?

The quality and intensity of a temperature sensation, excited by an object in contact with the skin, depend upon the relative conductivity of its substance, *i.e.*, the rate at which it absorbs heat from the body or radiates heat to the body, and upon its temperature relative to the temperature of the part of the body affected. The degree of temperature that excites no sensation of either heat or cold is called the *physiological zero*

point. Under usual conditions it is the normal temperature of the body.

D. *The rate of application of the stimulus.* Place a vessel filled with water over a Bunsen burner or spirit lamp. Plunge the hand into the water and allow it to remain in the water without movement. Let the water be heated gradually. Can the temperature of the water be considerably increased without your observing a heat sensation?

To produce a physiological excitation, all stimuli must be applied with some abruptness or suddenness. A frog placed in a vessel of water over a slowly augmenting source of heat can be boiled in the course of a few hours without making any sign of discomfort.

E. *Contrast of stimuli at the point of application.* Dip the hand up to the wrist in water of the temperature of the room. Hold in place for a number of seconds. Do you feel the pressure equally distributed over the hand or only a ring of pressure about the wrist? Thrust the arm slowly into the water. Where do you feel the sensation of pressure chiefly?

The physiological processes of the body are gradually accommodated to a stimulus, *e.g.*, the pressure of the water, and then cease to respond to constant stimulation.

F. *The sensitivity of moving parts of the body.*

1. Place a hair on a plate of glass or other hard, smooth surface, and over it lay ten or more sheets of ordinary writing paper. How many sheets of paper can you place over the hair and still detect it by passing the finger-tips back and forth over it? Can you feel the hair under the finger when resting the finger upon it without movement, either with or without the intervening paper?

2. Rest the finger-tip lightly upon a rough-covered book and

then move the finger over its surface. What difference in sensation do you notice? Close the eyes and touch the finger-tip successively to a rough-covered book and a smooth one. Can you distinguish between the two? Can you distinguish the difference as soon as the finger-tip is moved over the two surfaces? The relative sensitivity of active and passive touch can be exactly determined by using different grades of sandpaper.

Experiment XLII. **The production of sensations of specific quality by general stimuli — the specific energy of sense organs and nerve fibres.**

1. Rub with a menthol pencil the skin of the back of the hand. Tap the mentholized area and adjacent portions of the skin; wave the hand about; touch the mentholized area with a cold object, with a hot object. What are the resulting sensations?

2. Locate an isolated cold spot and tap the spot with a fine wooden point. Touch the cold spot with a slightly heated needle point that feels warm when applied to adjacent spots. Observe the resulting sensations. In making these experiments, try for comparison adjacent points on the skin.

A blow upon the ear will give rise to a sensation of sound. If the eye is struck, one may see stars. Steady pressure on the eyeball will cause a brilliant display of colored figures. When the optic nerve is cut, a sudden flash of light is seen. The application of menthol increases the sensitivity of the nerves to cold. It is maintained that a cold spot, when touched or pricked, will give rise to a sensation of cold only. When the back of the tongue is pressed, a bitter taste, sometimes a sour taste, is excited. It is claimed that a current of air applied to certain localities of the tongue gives rise to a salt taste. Some have reported a sweet taste from the use of cold water as a gargle. A current of electricity applied to the tongue excites a sour taste; applied to the optic or auditory nerve, retinal and auditory sensations

respectively; applied to the olfactory region of the nose, sensations of smell.

Such forms of energy as mechanical impacts, chemical irritation, heat, and the electric current appear to be capable of stimulating all the nerves of the body. When a sensory nerve is thus stimulated by any one of these forms of energy, the sensation that results is one appropriate to the particular nerve affected, and not to the particular stimulus employed. A flash of light results upon section of the optic nerve and the application of the electric current indifferently. Those stimuli which excite all nerves indifferently are distinguished as *general* or *inadequate* stimuli from the *specific* or *adequate* stimulus, to which a particular nerve and sense organ respond normally and most readily with their specific sensation, — as atmospheric vibrations for the ear and auditory nerve, light for the eye and optic nerve, heat for the nerves of heat and cold, mechanical impact for touch, chemical action for taste and smell. The fact that a sense organ and nerve, when excited by a general stimulus, respond with the same sensation that results from the specific stimulus suggests that the specific or distinctive quality of a sensation depends upon the "native" function of the nerve fibres and sense organs, and that the external stimuli are indifferent. "We feel our nerves," so this fact of sensation has been stated, "and not the external stimuli." The *theory of specific energy*, which maintains that the physiological processes of a sensory system, composed of nerve cells and fibres and sense organs, alone determine the quality of a sensation, probably exaggerates the indifference of the external stimuli. Nevertheless it calls attention to the important fact that our sensations are not always comparable to the external stimuli. Thus the sensation of white is a simple, unmixed sensation, but white light, its stimulus, is a mixture of many different rays of light; the difference between the sensation of red and the sensation of blue is a qualitative difference, a

difference in kind of sensation, although the respective stimuli, red and blue light, are both ether waves, differing only in vibration frequency and wave length.

Is the specific physiological process located more particularly in the sense organ, in the nerve fibre, or in the nerve cells of the brain center? At first the nerve fibre was selected as the seat of the specific sensory energy. The most striking structures of the eye and ear have nothing to do with the sensory process of seeing and hearing; the organs are for the most part mechanical structures whose function is to bring the external stimulus to act upon the true sensory structures. The rods and cones are the sensory cells of the organ of vision (see Diagram III, page 36), and the inner and outer hair cells on the basilar membrane of the cochlea are similar structures of the organ of audition (see Diagram XXXII, page 171). The function of the sensory cells is to excite the ends of nerve fibres terminating near them, when they have been acted upon by the external stimulus. But the nerve fibre may be excited directly by a physical stimulus without the mediate action of the sensory cells, as is common with the nerves of touch, which terminate freely near the surface of the skin (see Diagram XXIV, page 163). Reference to the diagrams will show the nerve fibres to be the processes of nerve cells situated between the sensory cells and the brain or spinal cord. The nerve cells from which proceed the fibres of the nerve of smell appear to be located in the olfactory membrane of the nose, close to the surface where they can be directly acted upon by the external stimulus. The elliptical cell of Diagram XXXVII, having a narrow upward prolongation and terminal hair-like processes, is an olfactory cell situated between the structural cells of the membrane. It is probably a nerve cell, for the nerve fibre seems to run direct from it to the brain. The sense apparatus of smell is least developed, from the anatomical point of view. The sensory cells of the retina are the most

highly developed. The sensory cells of the ear, and of touch and taste, are intermediate in degree of specialization (see Diagrams, pages 164, 166, and 171). But in all cases the function of the sensory cells, where such exist, is the stimulation of nerve cells and fibres connecting the sensory cells with the brain and spinal cord, and through other interposed cells ultimately with the specialized nerve cells in the cortex of the cerebral hemispheres. The direct stimulation of the nerve cells of the brain may also cause subjective sensations, the quality of the sensations depending upon the portion of the brain affected. A mechanical irritation,—for example, a piece of bone pressing against the brain substance, drugs that irritate the cells of the brain, and even abnormal variations in the blood supply,—may excite hallucinations of sight, hearing, taste, smell, touch, temperature, and pain. The vivid perceptions and sensations present during dreams also show that a central stimulation of the nervous substance of the brain may excite sensations which are oftentimes not distinguishable in quality from those received through the external stimulation of the sense organs. But this power of the brain to give rise to sensations when directly stimulated is developed only when the sense organs have been intact and have responded for a period of time to external stimuli. The loss of the sense organ of vision before the fifth year of life deprives an individual of all the visual elements of consciousness, though if the loss occurs after this period he may retain the power to have visual dreams and visual images of fancy. The specific character of a sensation is determined not by any one part of the physiological process,

DIAGRAM XXXVII. An olfactory cell and nerve fibre.

nor even by the entire physiological process alone, but by this and the external stimulus together; in the later life of an individual, one part of the physiological process, the brain cells, may acquire the power to respond with specific sensations to general stimuli. But the sensations and perceptions which are excited by electrical and other general stimuli are by no means so complex and various as are those excited in the normal way by the specific external stimulus. An intelligible explanation of the existence in our minds of different sensations must direct itself to an examination of (1) the inter-relations of the mental contents as such; (2) their relation to the particular structures and functions of the body; and (3) their dependence upon the specific stimuli of the physical environment.

CHAPTER VI

PSYCHO-PHYSICAL ANALYSIS

Experiment XLIII. **Qualitative analysis of sensations of sound.**

A. *Noise.* Procure eight wooden sticks such as are used in a xylophone or make them by cutting eight sticks of different lengths from a strip of wood about one inch wide and a quarter of an inch thick. Drop one of these sticks upon a table having a hard surface. Is the sound sensation a noise or a tone? Drop the eight sticks in succession. Is the tone quality then readily distinguished?

If resonators are to be had, employ these to hear the component tones of the noises you may hear about you, such as that made by scraping the foot over the bare floor. A resonator is a hollow chamber of such size that the enclosed air is thrown into sympathetic vibration by a sound wave of only one vibration frequency and not by others. Without the aid of resonators, if you have a good ear, you may still be able to hear the tones contained in many noises.

B. *Composite tones or clangs — timbre.*

1. Strike a note on some musical instrument, for example a violin, guitar, or xylophone. Can you detect a fundamental tone and several overtones in the resulting sound sensation?

2. Cause a string to vibrate and give a musical tone. Shorten the string by one-half. What is the musical relation of the pitch or quality of the tone of the half string to that of the whole string?

3. Cause a third of the string to vibrate; a fourth; a fifth. What is the musical relation of each of these tones to that of the whole string?

4. When the whole string is sounding loudly can you detect any or all of the tones that corresponded to the half, the third, the fourth, and the fifth of the string?

5. Strike the same note on a number of instruments. What is the difference between these tones of like pitch? Is timbre a difference in the quality of sensation or is it due to the combination of a number of tone sensations?

The string of a musical instrument vibrates at a certain constant rate. The tone sensation corresponding to the vibration rate of the whole string is its *fundamental* tone. The string, however, may vibrate also in aliquot parts; thus each half of the string may vibrate twice as rapidly as the whole string; each third at three times the rate of the whole string, each fourth at four times the rate, etc. The tone sensations produced by these vibrations of the aliquot parts of the string are called its *overtones*. Every musical instrument produces a composite of tones, called a *clang* sensation; the quality or pitch of the clang is given by its emphatic elementary tone — its fundamental. With this may be heard overtones having the pitch of tones of a vibration rate twice, three, four, five, etc., times that of the fundamental. If the fundamental can be represented in musical notation by C, the first overtone is C of the first octave above the fundamental; the second is G of this octave; the third, fourth, and fifth overtones are C, F, and G of the second octave, etc. Every musical tone is in reality a clang that can be analyzed psychically into a simultaneous group of tone sensations, and for each of the component tone sensations there is a stimulus represented by the vibration of the parts of a string, a column of air or other sounding body. The *timbre*, or so-called quality, of musical instruments and the human voice is dependent upon the relative number and intensity of the component overtones.

C. *Beats and roughness of clangs.* Allow two tuning forks of the same pitch to vibrate together. You will get a tone as though coming from a single fork of greater amplitude (intensity) of vibration. Weight the prong of one fork with wax and allow the

forks to vibrate together. Observe the very disagreeable beats. Repeat this procedure a number of times, increasing gradually the amount of wax. Do the beats increase in frequency? By adding wax can you cause them to pass into an indistinguishable roughness and finally to disappear?

Beats are due to an interference of atmospheric vibrations in opposite phase of wave motion. Two waves of water coming together so that their crests coincide will produce a wave higher than either. Coming together so that the crest of the one and the trough of the other coincide, they will interfere and perhaps obliterate the wave motion. Forks vibrating at the rate of 100 and 101 vibrations per second, respectively, will once in the second have alternately augmented and interfering wave crests. This alternate rise and fall in the intensity of the sound waves is the physical stimulus of the beat. If the forks differ by two vibrations there will be two beats per second. About forty beats per second is the limit of distinguishability for even acute ears. At this limit the beats give rise to a sensation of roughness. As the difference in the vibration rate of the two forks increases, the roughness gradually diminishes and finally disappears; a *difference tone* having a pitch corresponding to the vibration difference may be heard combined with the fundamentals and overtones of the two forks.

D. *The inter-relations of the component tones of clangs.*

1. Sound together a note and the second above, a note and its third, a note and its fourth, a note and its fifth; for example, C and D, C and E, C and F, C and G. Which pair gives the most pleasing combination?

2. Sound the notes of each pair in succession. Which pair gives the most pleasing sequence?

3. Combine a great number of tones as by striking many keys of the piano at once. Is the resultant sensation a noise? Is it displeasing? Why?

The most accordant combination of clangs is composed of a note and the first octave above. The combination of a note and its fifth, *e.g.*, C and G, is more pleasing than that of a note and its second, C and D. The reason for this appears from the accompanying table of the overtones of C, D, E, F, and G

Tone Combination.	Ratio of Vibrations of the Fundamentals.	Overtones in Order from the First to the Eighth. (Common overtones in heavy-faced type.)							
		1	2	3	4	5	6	7	8
C + c	1 : 2	C = **2**	3	**4**	5	**6**	7	**8**	9
		c = **4**	**6**	**8**	10	12	14	16	18
C + D	8 : 9	C = 16	24	32	40	48	56	64	**72**
		D = 18	27	36	45	54	63	**72**	81
C + E	4 : 5	C = 8	12	16	**20**	24	28	32	36
		E = 10	15	**20**	25	30	35	40	45
C + F	3 : 4	C = 6	9	**12**	15	18	21	**24**	27
		F = 8	**12**	16	20	**24**	28	32	36
C + G	2 : 3	C = 4	**6**	8	10	**12**	14	16	**18**
		G = **6**	9	**12**	15	**18**	21	24	27

and of c of the octave above, when these tones are in combination with C. The vibrations of C and c respectively are in the ratio of 1 : 2. No matter what the actual vibrations may be, the first eight overtones of C can be represented by 2, 3, 4, 5, 6, 7, 8, and 9, and the first eight overtones of c by 4, 6, 8, 10, 12, 16, and 18; to get the vibration rates of the overtones, we multiply the vibration rates of the fundamentals by 2, 3, 4, etc. Those overtones in the series of the first eight overtones which are common to both C and c are heavy-faced in the table. Every overtone of c is an overtone of C, and the fundamental

of c is the first overtone of C. The composite clang C + c contains no elementary tones which are not actually present in the simple clang C. When a note and its second are sounded together, C + D, the vibration frequencies of the two tones are in the ratio of 8 : 9. An inspection of the table giving the overtones of these two notes will show that the eighth overtone of C and the seventh of D are the first overtones common to both notes. The combined clang C + D is composed of many dissimilar elements, whereas the combined clang C + c is constituted of similar elements. The combination of a note and its fifth, C + G, contains component fundamental tones the vibration rates of which are in the ratio of 2 : 3. Within the first eight overtones, these notes have three overtones in common, the second, fifth, and eighth overtones of C and the first, third, and fifth of G. The combination C + E has only one common overtone within the first eight, the fourth of C and the third of E. The combination C + F has two common overtones within this range, the third and seventh of C and the second and fifth of F. Arranged in the order of similarity of components, these clangs fall into the following sequence: (1) C + c; (2) C + G; (3) C + F; (4) C + E; (5) C + D. The higher the order of an overtone, the less is its intensity. The common overtones of C + D, being in the seventh and eighth order respectively, are so weak as to be practically negligible. Moreover two overtones may give beats if their vibration rates are close enough together. C + D contains overtones that would give rise to beats; these give to the combination a characteristic roughness and unpleasantness.

The aesthetic value of clang combinations — *i.e.*, harmony — is largely dependent upon the absence of beats and roughness and the relative intensity of common overtones. The similarity of the components of clang combinations must not be so great as to constitute practical identity, if the combination is to produce a pleasing effect. The combination C + c is not

so pleasing as the combination C + G, because of the practical identity of c with C. The same principles underlie the aesthetic effect of tones in sequence. The succession of tones in a melody is determined also by the relative degree of similarity and variety in the clang components. Noises are clang combinations containing relatively the largest number of unlike overtones along with fundamentals and overtones producing beats and roughness. It is contended by some psychologists, however, that after all the tones have been separated from a noise a specific "noise" sensation remains. These psychologists recognize two classes of simple, *i.e.*, unanalyzable, sensations of sound — *tones* and *noises.*

The simple tone sensation is an abstraction of analysis, all external musical tones being composed of a fundamental and overtones. A simple tone sensation would be received from an atmospheric vibration of a single constant rate. Tuning-forks have been constructed to give approximately simple tone sensations. The siren, also, is a source of vibrations relatively free from overtones. But even when the external vibrations are of one frequency only, the organ of hearing itself may contribute the overtones.

Experiment XLIV. **The quality and intensity thresholds of sensations of sound.**

A. *The initial intensity threshold.* Let the subject be seated in a quiet room, and keep the eyes closed and head steady. Hold a watch close enough to his right ear to be distinctly audible. Move it slowly away from the ear, along a line perpendicular to the median vertical plane of the head, until the subject announces that he is unable any longer to hear the ticking. Measure the distance. This is the "just unnoticeable" distance.

Begin with the watch at a distance from the right ear somewhat greater than the just unnoticeable distance, and move the

watch slowly in toward the ear until the subject announces that he is just able to hear the ticking. This is the "just noticeable" distance.

Repeat these two experiments four times each and get the "average just noticeable" and the "average just unnoticeable" distances. Add these together and divide by two to get the "initial intensity threshold" of the sound of the ticking watch.

Obtain in the same way the initial threshold for the left ear. The two thresholds make possible an estimation of the relative sensibility of the two ears.

B. *The initial and final quality threshold.*

1. Use for the purpose of this experiment a siren connected with bellows. As the disc of the siren begins to rotate, separate puffs of air will be heard escaping through the holes of the disc. The number of puffs per second increase with the rate of rotation of the disc. When they have a frequency of about thirty or forty per second, they will no longer be heard as separate puffs of air but will give rise to the sensation of a tone of low pitch. The siren is provided with a dial upon which a moving hand records the number of rotations of the disc per second; from this can easily be calculated the number of interrupted puffs which give rise to the tone of lowest noticeable pitch, *i.e.*, the initial quality threshold.

The final or upper threshold of sound quality may be obtained by using a Galton's whistle. The high shrill note is gradually increased in pitch by screwing down the plunger of the whistle until a tone sensation no longer results from the rapid vibrations of the escaping air. Steel bars or tubes marked with their respective vibration rates may also be employed.

The atmospheric waves, radiating from a sounding object, preserve their form and vibration frequency, but diminish in amplitude as the distance from the source of sound increases. The quality of the tone sensation depends upon the vibration frequency; the intensity upon the amplitude of the vibration. For this reason, the greatest distance at which the sounding

body is capable of giving rise to a sensation of sound can be taken to measure the least intensity of a stimulus sufficient to give rise to a sensation. Above this initial threshold value of the stimulus, the vibration amplitude may be indefinitely increased. The final threshold of sound intensity cannot be determined, because a stimulus of great intensity will cause the destruction of the tympanum.

EXPERIMENT XLV. **The intensity threshold of sensations of single quality.**

A. *The initial threshold of touch.* Use Scripture's touch weights to determine the smallest possible weight, measured in milligrams, that will give rise to a sensation of touch. Beginning with the smallest weight, apply them successively in order of weight to the palm of the hand or other portion of the subject's body. Screen from the subject's view the part to which the stimulus is applied. The twenty circles of cardboard one centimetre in diameter vary from one to twenty milligrams in weight. The initial threshold of touch sensation is expressed in terms of the impact exerted by the weight giving rise to the just noticeable sensation.

B. *The initial threshold of taste qualities.* Prepare two solutions respectively of salt and sugar by dissolving ten grams of each in one hundred grams of distilled water. Measure off a small quantity of one solution, say a gram. Is the characteristic taste quality recognizable on sipping? If so, add a gram of water to a gram of the solution. Stir thoroughly and taste as before. If the taste can still be recognized, add another gram of water to a gram of the last solution and continue until you are no longer able to detect the taste of the liquid. Compare the percentage of sugar and salt respectively in the solutions which first give no sensation of taste. The thresholds for bitter and sour may be measured in terms of solutions of quinine and tartaric acid.

C. *The final threshold of pressure sensation.* Take the pressure algometer and press with considerable force upon the ball of the thumb of the right hand. Ask the subject if he feels a sensation

of pain only or if the pain is combined with pressure. If a pressure stimulus can give a pain sensation of such intensity that the pressure sensation is suppressed by the stronger pain sensation, we are then above the final threshold of the pressure sensation. In such case the pressure may be taken below this final limit and increased until the subject announces that he just begins to experience pain alone. Five trials should be made and an average measurement obtained in kilograms. This value measures the final threshold of pressure sensibility.

The initial threshold of these sensations is both a qualitative and an intensive threshold. Sound sensations alone have two distinguishably different thresholds, one of quality and one of intensity; retinal sensations have but a single threshold, that of quality.

Experiment XLVI. **The discrimination of small differences in the quality of sensation; the difference threshold.**

Take two tuning-forks of exactly the same number of vibrations per second, and hence giving tone sensations of the same quality or pitch. Strike them in succession, allowing each to vibrate for about a second with a second's interval between. Stick a small quantity of beeswax on the end of a prong of one fork and cause the forks to vibrate in succession as before, striking the weighted fork last. Inquire of the subject whether the two forks appear to differ in tone and if so which of the two is the higher. If the subject reports that the forks seem to be of the same pitch, add more wax to the weighted fork. Continue until the subject is quite sure that he observes a difference in pitch between the two forks. Determine the objective difference in the vibration rate by allowing the two forks to vibrate together and thus give rise to beats. The number of beats per second is equal to the difference in the number of vibrations per second. This is the "just noticeable amount of difference."

Now increase the difference between the two forks by using a considerable amount of wax. Sound as before, and the subject will notice clearly and distinctly the difference in pitch. Diminish the amount of wax until the subject says the two forks seem to have the same pitch. Measure the difference in vibration rate. This is the "just unnoticeable amount of difference."

Repeat each of these experiments until you get five measurements of the just unnoticeable difference and five of the just noticeable difference. Average each set of results. Add the average results and divide by two. The final result is a difference threshold of tone quality.

Experiment XLVII. **The discrimination of small differences in the intensity of stimuli; the psycho-physical methods; the psycho-physical or Weber's law.**

A. *The method of minimal gradation, also called the method of just noticeable amount of difference.*

1. Let a subject hold in his hand a wide-mouthed bottle of not very thick glass partly filled with sand so as to be of some convenient weight, *e.g.*, a hundred grams. Let the subject close his eyes. Pour gently a constant stream of sand into the bottle thus held by the subject. Have the subject call out, "Now," as soon as he notices a change in the weight of the bottle. Weigh the bottle with its increase of sand and subtract from this the weight of the bottle and its contents at the beginning of the experiment. This difference in weight is the just noticeable difference of intensity. It is called the "upper" difference threshold of intensity.

Place in the hand of the subject a bottle of the same weight as before. Let the subject having his eyes closed tilt the bottle, pouring the sand slowly from the bottle until he notices a difference in weight. Calculate the difference between this and the original weight. Obtain the average result of five experiments. This value measures the "lower" difference threshold of intensity.

2. The customary procedure in accordance with this method gives the subject a standard stimulus to which he can refer the

changing comparison stimulus. Place two bottles partly filled with sand and of equal weight, one in each hand of the subject. Increase as before the weight of the bottle in the right hand until the subject is just able to notice a difference. Record the objective difference in weight as the just noticeable amount of difference. Take the comparison weight considerably heavier than the standard weight, and proceed to obtain the just unnoticeable amount of difference. Make ten experiments and get the average upper difference threshold. Obtain by a similar procedure the average lower difference threshold. Add the upper and lower values and divide by two. The resultant value is the just noticeable difference threshold.

3. Require the subject to lift both weights with the same hand, preferably the right. The comparison weight must then be successively increased or decreased by small amounts. In giving his judgment of the relative weight of the stimuli, the subject lifts one weight after the other with a single movement of the hand and arm lasting about one second and allowing a second's interval between the lifting of the first and second weights. The standard weight should be lifted first in one half of the trials and second in the other half. This procedure should be followed in conducting experiments by all of the psycho-physical methods. The standard stimulus should be compared with each weight of the comparison stimulus only once, an immediate judgment being insisted upon after each trial.

With the method of just noticeable difference, the just unnoticeable upper and lower thresholds are determined by the procedure described in Experiment XLVI, and are combined with the just noticeable thresholds. The upper and lower thresholds of difference should be calculated separately and afterward combined to obtain the average threshold of difference.

B. *The method of unnoticeable difference, or method of average error.* Take a standard weight, *e.g.*, 100 grams, and a comparison weight considerably above or below it. Let the subject make the comparison weight equal to the standard weight, lifting the weights successively with one hand. When the subject reports that the two weights seem to him alike, weigh the comparison weight exactly in

the balance and then calculate the amount of error. Make five experiments beginning with the comparison weight lighter than the standard and five with the comparison weight heavier. Average the two sets of five results separately. You will thus have two average errors which may differ slightly, depending upon the direction of change in the comparison weight. Calculate the average variation of each error from the average error. The average error records the constant tendency toward an over- or under-estimation; the average variation, also called the average variable error, records the constancy with which the subject approximates to the standard weight. The constant error and the variable error are dependent upon different causes.

C. *The method of right and wrong cases.* Take weights of 100, 101, 104, and 112 grams of the same size and external appearance. Require the subject to lift two weights in succession, giving one second's stimulation and one second's interval. Let one of the two weights be always the standard weight of 100 grams. Make thirty experiments, *i.e.*, ten with each of the comparison weights. With each pair of weights, for example with 100 and 104 grams, let the subject lift the heavier weight first in five of the ten trials and last in the other five trials. Require the subject always to judge, even though it be the merest guess, which of the two weights presented him in pairs is the heavier. Record his judgment as right or wrong as the case may be. For each comparison weight, ascertain the percentage of times the subject is right in his judgment. Does the correctness of judgment increase from a mere guess to certainty as the comparison weight increases? Do you consider the threshold to be the amount of difference required to give 50 per cent, 75 per cent, or 100 per cent right cases?

This experiment can hardly give satisfactory results with less than one hundred experiments with each pair of weights.

D. *The method of the estimated amount of difference, also called the method of supraliminal difference.* Take two standard weights of 100 and 112 grams. Give the subject a third box nearly equal in weight to one of these and require him to add to or subtract from the weight of this box until its weight seems midway between that of the other two. Make five trials and get an average result and

an average variation. Is the average result the arithmetical or geometrical mean of the two standard weights?

Take two boxes, one filled with sand weighing 100 grams, the other empty. Require the subject to fill the second with sand so as to weigh twice as much as the first box. Make five trials and obtain the average result and average variation. Repeat for one-half, three times, and five times the weight of the standard stimulus.

E. *The increase of the difference threshold in proportion to the increase of the intensity of the stimulus.*

Repeat the experiments, employing one or all of the methods, using standard weights of 50 and 200 grams.

Compare the respective results with weights of 50, 100, and 200 grams. Is the threshold of difference constant for all intensities of the standard stimulus or does it increase in the same proportion as the intensity of the stimuli?

Suppose the intensities of two similar stimuli to have a value of 100. These stimuli may be two weights of 100 grams or two sound waves originated by a ball dropping upon a plate from a height of 100 inches, etc. If the intensity of one of a pair of equal stimuli is successively increased by very small amounts, *e.g.*, by one, two, three grams, etc., a difference between the greater stimulus and the stimulus of 100 will not be observed at once. Let us suppose that when the greater stimulus is made equal to 120, a subject is just able to distinguish the greater stimulus from the smaller. Let us suppose further that when the intensity of a stimulus has a value of 50, the subject can distinguish equally well between it and a stimulus of only 60. When we give the stimulus a value of 200 and take as a comparison stimulus one of 220, the subject will fail to notice that they are different. In this region of the scale of stimuli intensities, the difference must be made equal to 40, in order that he may perceive them to be different. We have now assumed that the stimulus of 50 must be increased by 10, the stimulus of 100 by 20, and the stimulus of 200 by 40, in

order that each stimulus be distinguished respectively from another that is greater by the least perceivable amount. If experimentation with various stimuli gave nearly similar results, we could express the general result in the form of a law that *the least amount of perceivable difference is a constant proportion of the intensity of the stimulus.* In the case assumed the relative difference just noticeable is $\frac{1}{5}$ of the stimulus. To the quantity 100 must be added $\frac{1}{5}$ of itself, or 20, to obtain two stimuli distinguishably different. To the stimulus 120, $\frac{1}{5}$, or 24, must be added; to 144, 28.8 must be added. A series of values, 20, 24, 28.8, 34.6, etc., will be developed by this procedure; each number of the series measures a just noticeable amount of difference in the ascending scale of stimuli. If we represent graphically, as in Diagram XXXVIII, the quantity 20 by a line $\frac{1}{2}$ inch in

DIAGRAM XXXVIII. The just noticeable increment of the stimulus represented graphically by proportional lengths of a straight line.

length, the increment 24 will be represented by a line proportionately longer; the increments 28.8 and 34.6 by increasingly greater lengths of line. The line represented above is divided into four parts that have the proportions necessary to give a graphic representation of these progressive increases in the magnitude of the increment.

Let us designate by the letter S the sensation to which the stimulus 100 gives rise and by S^2, S^3, S^4, and S^5, respectively, the sensations due to the stimuli 120, 144, 172.8, and 207.4, which are obtained by adding the increasing increments. These five sensations will constitute a series of increasing intensities. This fact of sensation can be represented, as in Diagram XXXIX, by a continuous straight line along which will fall at different points the sensations S, S^2, S^3, S^4, S^5. Let a point on the horizontal line of this diagram be taken to stand for the position

of the stimulus 100. If, as before, the just noticeable increment 20 be represented by a length of ½ inch, and we measure a stretch of this length to the right, we fix on the line the position of the just noticeably greater stimulus 120. Continuing

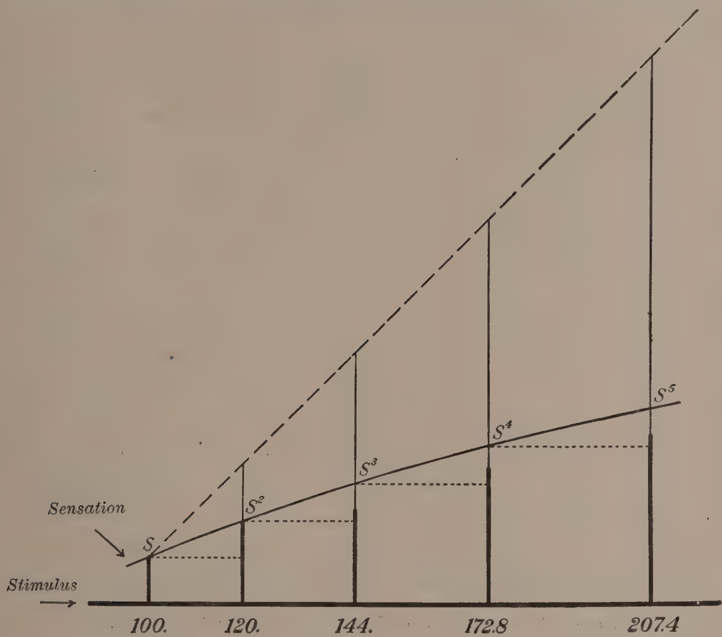


DIAGRAM XXXIX. Graphic representation of the relation of increases in the intensity of a stimulus to the increases in the intensity of the sensation.

this procedure, we place upon the line 144, 172.8, 207.4 at distances determined by the just noticeable increments. From the point of the horizontal line which represents the stimulus 100 we may erect a vertical line to represent the sensation *S*, corresponding to the stimulus. The intensity of *S* is unknown. There are no mental units of measurement similar to grams and inches in terms of which to express the intensity of the sensation relative to that of the stimulus. But the sensation has

some intensity, and, whatever this may be, a line of an arbitrary length, say $\frac{1}{4}$ of an inch, may be taken to represent it. From the point 100 of the horizontal we then measure off a vertical line $\frac{1}{4}$ of an inch in length. This will not mean that the intensity of the sensation is $\frac{1}{2}$ that of the stimulus, but only that the sensation has some as yet unknown value. From the upper end of the vertical line an oblique line (the line of dashes in the diagram) drawn to the right would contain a continuous series of increasing sensations; the increasing distance of this oblique line from the horizontal line of stimuli would express the fact that sensations increase as their stimuli increase.

If it were a fact that sensations increased by the same amount as do the stimuli, the line of increasing sensations would have the direction of the line of dashes in the figure. The length of the vertical line S^2, included between the horizontal and oblique lines, is equal to the length of the line of S plus the length that was taken to represent the increase of stimulus 120 over 100. Verticals representing S^3, S^4, and S^5 will each be increased by the respective increments of their stimuli. Experimentation and common experience demonstrate that the increase of sensation becomes relatively smaller as the stimulus becomes greater. A line to represent this fact of sensation will need to be so drawn as to bend toward the horizontal line the farther it extends to the right. The line of sensational increase will, therefore, be a curved line, say for the moment, the continuous curved line of the diagram.

It has been supposed that the psycho-physical law enables us to determine the exact course of this curved line of sensation. It will be remembered that stimulus 120 is just noticeably greater than stimulus 100. It seems to follow from this fact that S^2 is also just noticeably greater than S. What the amount of this difference would be if we were able to measure the intensity of the sensations directly as we can measure the intensity of the stimuli, psychology is not able to say. But we

can say that there is at least some difference between S^2 and S, and we may represent this fact by drawing a heavy vertical line from the horizontal to S^2, making it longer than S by some arbitrary amount. When we come to erect the vertical line of sensation for the stimulus 144, we are again in doubt as to what length of line to employ. As S^3 is the sensation received from a stimulus just noticeably greater than the stimulus of S^2, we can also draw the sensation line of S^3 somewhat longer than the sensation line of S^2, for example the heavy portion of the vertical line erected at the position 144 on the horizontal line.

The exact length of vertical line necessary to represent the relative intensity of the sensation S^3 depends upon the actual difference of intensity assumed to exist between S^3, S^2, and S. No one of these sensations can be measured by itself, nor can any two give a satisfactory measure. It has been assumed, however, that, inasmuch as the stimulus of S^3 is noticeably greater than the stimulus of S^2, and the stimulus of S^2 is noticeably greater than that of S, we may consider that the sensation S^3 differs by the same amount from S^2 as the sensation S^2 differs from S; in consequence, $S^3 - S^2 = S^2 - S$. This would permit us to draw the sensation line of S^3 as much longer than S^2 as S^2 is longer than S. This is the length of the combined heavy and fine line from the horizontal to S^2. As soon as we have determined the relative lengths of the three sensation lines for S, S^2, and S^3, we can draw a continuous line connecting the points ascertained and extend this to the right to represent sensations of intensities which have not as yet been examined. On the assumption that sensations of all intensities are related to their stimuli, as are the three sensations S, S^2, and S^3, three points are sufficient to establish the line to be a curve and to determine exactly its entire course. The curve will cut the sensation lines of S^4 and S^5 at such points that $S^5 - S^4 = S^4 - S^3 = S^2 - S$. In other words, *the sensations increase by constant quantities when the stimuli increase by constant*

proportional amounts of the stimulus. If this interpretation of the facts of these experiments is a correct one, we may change the expression of the psycho-physical law to one of the two following forms: *If the sensations are to be increased by a constant amount, the stimulus must be increased by a constant ratio*, or *Sensations increase in an arithmetical series of progression when the stimuli increase in a geometrical one.*

Two series of quantities so related to one another that the one series varies arithmetically when the other varies geometrically are in the logarithmic relation. If any one quantity of either series is known, its corresponding quantity in the other series may be calculated. It appears to follow from the mathematical formula of logarithms that the intensity of a sensation is measurable in terms of the logarithm of the intensity of its stimulus. This form of the psycho-physical law, which may be called Fechner's law, involves the further assumption that the constant just noticeable difference between any two sensations is equal to the first just noticeable sensation. The unit of progression in the arithmetical series of sensations is therefore the just noticeable sensation, which repeats itself by addition, appearing throughout the series of intensities as the just noticeable amount of difference. If the letter C designates the constant multiplier required by the mathematical formula and varying for each group of stimuli, S the intensity of the sensation, and s the intensity of the stimulus, Fechner's law may be expressed thus: $S = C \log \cdot s$. Through this formula one may apparently measure sensation in terms of the stimulus, even though the sensation itself cannot be directly measured.

Are we justified in thus interpreting the facts of psycho-physical experimentation? Is the just noticeable amount of difference a constant quantity of sensation successively added to the sensations in a series of increasing intensities? In psycho-physical experimentation, the subject is given two stimuli of different intensity. We get from him the judgment

that they are alike or the judgment that they are unlike. Stimuli ranging from 100 to 119, inclusive, he tells us are exactly alike; in this he is wrong. The stimuli 100 and 120 he informs us are different; in this he is right. It is an arbitrary assumption of the psychologist that the only factor determining the correctness of the judgment is the amount of difference between the intensities of the two sensations. Many processes are interpolated between the application of the stimuli and the announcement of a right judgment. There are the sense organs, the nerves and the brain on the physiological side; there is the factor of apperception, of preperception, of the associated mental contents which constitute the subject's knowledge of the actual stimuli — all these contribute to form the resulting judgment. The facts of the experiment give the psychologist no knowledge of the various processes concerned, excepting only (1) the actual difference between the stimuli and (2) the rightness or wrongness of the subject's judgment. What physiological and mental processes may have conspired to determine a right judgment in one case and a wrong judgment in another must be inferred from facts other than those obtained from the experiment.

The methods employed to discover the relation of sensations to stimuli and to prove the psycho-physical law have all been illustrated in the simple experiments with the lifted weights above. The *method of minimal gradation*, by which one of two equal stimuli is changed until the two stimuli are *just noticeably different*, would seem at first sight the one best calculated to give direct results. The subject himself says when he notices a difference. Criticism and practice alike demonstrate this method to be distinctly unsatisfactory. Subjects differ greatly as to the amount of difference they call "just noticeable." These experiments serve to reveal the personal opinions of different subjects as to what the noticeable difference is, rather than to determine the actual difference of stimuli that is just noticeable.

The *method of estimated amount of difference* also seems to deal directly with sensations. The subject is given two stimuli and is asked to produce a third stimulus that will give a sensation midway between the two sensations of the given stimuli, for example to estimate the weight of three boxes, so that the sensation of weight received from one shall seem to him midway between the two others. This method also involves the subject's opinion and knowledge. It is found in practice that the subject will choose a stimulus which, for some external reasons, he believes to be midway between the two other stimuli. Thus, in lifted weights, a weight of four pounds may be placed midway between one of two and one of six, the subject endeavoring to calculate what a weight of four pounds feels like rather than to produce a weight that gives a sensation standing midway between the sensations from two and six pounds respectively. The unreliability of this method is evident when the subject is asked to produce a stimulus two, three, or four times as great as the one given him. This he can do fairly well in weights, because if he is given a weight of one pound, he tries to produce weights of two, three, and four pounds, but with other stimuli, such, for example, as sound, the judgments are exceedingly unsatisfactory. It is impossible to say whether one cup of coffee sweetened with sugar tastes two, three, or four times as sweet as another cup.

The *method of right and wrong cases* is an important contribution of psychology to science. By this method, the subject can be kept entirely ignorant of the objective relation of the stimuli. He is given, for example, two weights and asked to decide which is the heavier. His judgment will be either right or wrong. This is recorded. In a hundred trials with stimuli differing by small amounts, he will be right a certain percentage of times and wrong a certain percentage of times. If he is fifty times right and fifty times wrong, the result differs in no wise from chance. A coin tossed into the air is expected

to fall fifty times "heads up" and fifty times "tails up." If the subject is right one hundred times in the one hundred trials, he has undoubtedly had something to go upon in distinguishing the stimuli. But if he is right 75 per cent of the times, there is also evidence, though not so certain, that the difference between the stimuli is sufficient to determine a judgment in the one direction rather than in the other. If a coin should fall heads up one hundred times, or even seventy-five times, in a hundred throws, we should infer that the coin or its thrower in some unknown manner determined the result. The percentage of right judgments rises from 50 to 100 as the difference between two comparison stimuli is taken greater, and the evidence becomes stronger that the subject has had some difference in sensation to go upon in forming his judgment of the difference between the stimuli. The amount of difference sufficient to give 75 per cent of right judgments is usually regarded as the just noticeable amount of difference. A smaller amount of difference will, however, be noticeable in a smaller percentage of cases and a larger amount of difference in a larger percentage of cases.

The experiment, then, deals with two stimuli and with a mental reaction to the stimuli that is either a right or a wrong judgment. Upon what the judgment is based, the experiment itself does not disclose. It does tell us that similar reactions, namely a right judgment, will occur 75 per cent of the trials if the stimuli differ by a certain proportional amount. That the difference in the process of sensation is an important factor cannot be doubted, but this difference is not the only factor. Even if we eliminate such factors as the time and order of stimulation, the interval that elapses between the two stimuli presented and the direct knowledge of the actual stimuli employed, we cannot exclude from participation in the determination of the mental result such factors as the physiological processes in sense organ, nerve, and brain and those mental processes which

we have described under the terms of "association," "preperception," and "apperception." To assume that the sensations differ by a just noticeable amount because the stimuli differ by a just noticeable amount is to ignore all the factors that are concerned in the formation of a perception, excepting alone the intensity of the sensation. Even if we assume that the sensation is the factor that contributes most largely to the mental result, we cannot be assured that the difference in sensation is entirely a difference of intensity. If every increase in the intensity of a stimulus caused the sensation to differ in quality, we might judge the intensities of the stimulus quite as well as if the sensation changed in intensity. We might even have formed the habit of calling changes in quality by the name "intensity" because of the unavoidable tendency, several times discussed in the course of this Manual, to apply physical analogies to mental facts. This happens to be the case with temperature sensations. Because the physical stimulus of a heat sensation differs only in intensity from the stimulus of a cold sensation, many wrongly state that the two sensations differ also in intensity, and thus, if the analogy is carried out strictly, make the heat sensation an intense cold sensation, — a manifest absurdity. Heat and cold are two qualitatively different sensations, arising from different degrees or intensities of the same form of energy, *e.g.*, heat. In the case of light also, we naturally think of the "quality" difference between red and a shade or tint of red as a difference of intensity, because we associate these differences with the physical intensity of illumination.

The fact remains, however, that the subject does judge two stimuli to be just noticeably different when the amount of change is an approximately constant proportion of the intensity of the stimulus. This fact is one of no small importance and well deserves formulation as a psycho-physical law. The mental result of a stimulus is the perception of one external

object. The mental result of two stimuli differing by a certain amount is the perception of two just noticeably different objects. To obtain the same mental result from two other stimuli of greater absolute intensities, the amount of difference between the two stimuli must be increased in proportion to the increase in the absolute intensity of the stimuli. As stimuli increase, a greater amount of the stimulus will be required to produce the same mental reaction. The psycho-physical law is in effect a law of diminishing mental returns from increasing stimuli. Psychology is not the only science to frame a law of diminishing returns.

Although the method of right and wrong cases is the one which best reveals the relation of the mental reaction to small differences of stimuli, the method is nevertheless more exact than is necessary to ascertain differences in reaction to sensory stimuli. The method of right and wrong cases requires many hundred experiments to establish any result at all; by the *method of average error*, ten experiments, in some cases even a single test, suffice satisfactorily to establish an exact measure of the sensitivity of a given subject. This method is therefore most serviceable and sufficiently exact for comparative measurements in statistical and child psychology.

Weber, after whom the psycho-physical law was named, expressed the results of the simple experiments which initiated so much discussion and investigation in the following words: "*In the discrimination of objects that are compared the one with another, we do not perceive the difference between the objects but the ratio of this difference to the magnitude of the compared objects.*" This statement of the results of Weber's experiments is not a law of sensation, but a law of perception, *i.e.*, of the complex processes of observation and discrimination. The psycho-physical law as thus formulated is a most important contribution to science and gives exact expression of the facts. It contains no reference to the relative magnitudes of sensations and stimuli. It does not maintain nor does investigation demonstrate that

the perceivable proportion is constant. In fact, with the greater number of stimuli the perceivable proportion is variable, being greater in some ranges of intensity and smaller in others. Only with a limited number of stimuli, and even with these only in ranges of medium intensity, does the perceivable proportion seem to remain fairly constant. In Fechner, to whose tireless investigation we owe an inspiring model of scientific patience and accuracy, was found combined the man of science and the ardent mystic. Perhaps the trend of his mind toward mysticism was responsible for his reading into the results of his scientific experiments much that they did not contain. The results of these experiments — as many as 76,072 experiments by the method of right and wrong cases with lifted weights alone — he formulated as a universal law establishing a fixed numerical relationship between sensations and stimuli. On the assumption that the world is divisible into mind and matter, and that the mind's knowledge of matter is based entirely upon the sensations which it receives from the external world, the psycho-physical law became for him a constructive principle of the universe. In generalization it is second to none, not even to the principle of the conservation of physical energy established by Fechner's contemporary, Helmholtz. No criticism can touch the methods of Fechner nor the unswerving devotion to science with which he carried them out. The work of Fechner remains an ideal of scientific attainment and a valuable contribution to the facts and principles of psychology. The peculiar interpretation which he put upon those facts was due to no deficiency of observation or method. The particular form of the psycho-physical law in which Fechner expressed his results was determined by preconceptions of the nature of sensation and theories of a necessary relation between mind and matter; Fechner prejudged the results of the experiments before he had lifted a single weight.

CHAPTER VII

THE SENSATION AS THE MENTAL ELEMENT

EXPERIMENT XLVIII. **The mental contents that are called sensations of taste are generally combinations of taste with other sensations.**

Place upon the tongue, holding the nostrils closed so that the odor of the object may not be perceived through the posterior nasal cavities, small quantities of scraped apple, potato, turnip, or beet. Can you distinguish between these objects by taste alone?

Can you distinguish between water, tea, and coffee if a few drops only are placed upon the tongue? Do they seem to you different in taste? If so, in what respect do they differ?

How many different qualities of taste do you think you can distinguish?

Describe ten different odors with which you are familiar. Can you give names to odors? Can sensations of smell be arranged in a continuous series? Are sensations of smell greater in number than sensations of taste?

There are but four recognizably different taste sensations. These are the sensation of sweet, of salt, of sour, and of bitter. All other taste sensations are combinations of these four tastes proper with sensations of touch, sensations due to the chemical action of a substance upon the tongue, sensations of heat and cold, and sensations of odor. It is practically impossible to distinguish one flavor from another by taste alone. Tea and coffee mixed with milk, as in the customary breakfast cup, are indistinguishable from hot milk by the sense of taste alone. Taste sensations comprise four qualities not related to one another as are color sensations. If they are to be represented

diagrammatically they cannot be placed on the same straight line as are auditory sensations, but must be represented by four different lines, one for each quality. Each line then represents all possible variations in the intensity of each taste.

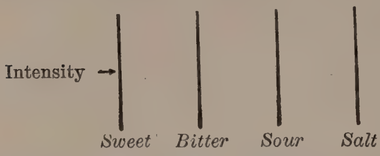


DIAGRAM XL. Graphic representation of taste qualities and intensities.

The qualities of odors are much more numerous than those of taste. Scientific analysis has not been able to arrange odors in a satisfactory classification according to common properties or characteristics possessed by different groups. This is quite in accordance with the inability of language to find appropriate names for odors similar to those for taste. Odorous substances are distinguished only with reference to the objects which give rise to similar odors, as a violet odor, a pitchy smell. The qualities of smell are manifold, but do not arrange themselves in a continuous series as do sensations of sound and color.

EXPERIMENT XLIX. **The psychical discreteness of heat and cold sensations.**

Touch to the skin some metal object heated to a temperature greater than that of the body. Allow it to cool gradually until it ceases to give a sensation of heat. Cool it considerably below the temperature of the body and observe the sensation of cold which you receive from it. Allow it to increase in warmth until it feels neither cold nor hot. Does the sensation of heat differ in quality or only in intensity from that of cold?

A confusion of the standpoint of psychical analysis with the physical standpoint is apt to cause the psychologist as well as the student to look upon the sensation of cold as merely intensively different from the sensation of heat. If one regard only the mental characteristics of the sensations, heat is one

sensation of varying degrees of intensity, and cold is a qualitatively discrete sensation also presented in varying intensities. Thus there are two qualities of temperature sensation, heat and cold, each having a considerable range of possible intensities. A single line will represent the sensations of heat, any point in

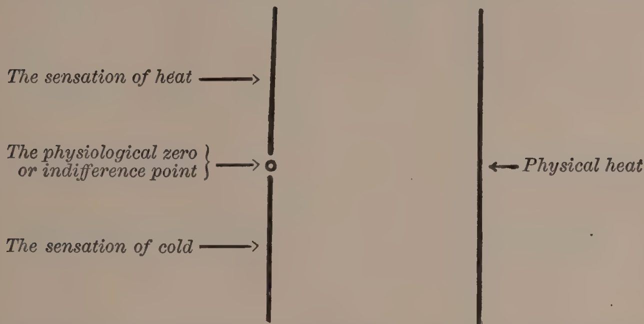


DIAGRAM XLI. The relation of the sensations of heat and cold to the physical stimulus, viz., heat of different degrees of temperature.

the line standing for a heat sensation of a given intensity. But a second line, not continuous with the first, is needed to represent the intensities of the cold sensation. The physical stimulus of both heat and cold, on the other hand, can be represented by a continuous straight line, because there is no break between those temperatures which are below the normal temperature of the body and those which are above. The break in sensation, however, between the mental result of a temperature lower than the physiological zero point and the mental result of a higher temperature amounts to a distinct difference in quality.

It is sometimes difficult to tell whether the water into which the hand may be suddenly thrust is hot or cold. In fact, it often feels both hot and cold. If there are heat nerves which give rise to heat sensations and separate cold nerves which give rise to cold sensations (see page 163), it is possible for an excessive heat stimulus to affect both sets of nerves; thus hot water

or an excessive cold stimulus may excite both the cold nerves and the heat nerves. A very cold object actually burns the tissue of the skin in the same way that a hot object does. It is therefore possible to receive both a heat and a cold sensation from the same object. It is also possible for the same object to give rise first to a sensation of heat, because it has first stimulated the heat nerves, and then to a sensation of cold, as the cold nerves become subsequently affected.

EXPERIMENT L. **The so-called feeling tone of sensation.**

Press gently the point of a pencil against the skin. Increase gradually the pressure until it becomes distinctly painful. Do you notice the sensation of touch changing gradually to one of pressure and then to one of pain? Is the sensation of pressure an intense touch sensation? Do you seem to get an isolated pain sensation or is there always a pressure sensation mixed with the pain sensation? Would you consider the pressure and the pain to be two different sensations or is the pain in this case only a painful pressure sensation?

Touch a very hot object to the skin of the arm or hand so that it gives a decided sensation of pain. Describe the resultant sensation or sensations. Do you feel three sensations, touch, heat, and pain simultaneously, or do you observe them in a characteristic succession?

Swallow a piece of ice. Does it feel cold after it is in the stomach? Is it painful after it is in the stomach? Do hot tea and coffee feel hot in the stomach or only painful? Can you distinguish between a pain sensation, a disagreeable feeling, and the bodily reaction to a pain or disagreeable feeling? If so, in what respects do they differ?

The pencil point when touched gently to the skin gives rise to a distinctive touch sensation; when the intensity of this impact is increased, the sensation is more apt to be described as a pressure sensation. Because the pressure stimulus is

simply an augmentation of the touch stimulus, one is inclined to consider the pressure sensation as an intense touch sensation. A due regard for the strictly mental likeness and unlikeness of the sensations should lead us to distinguish the pressure sensation as one qualitatively different from the touch sensation. If the intensity of the impact be again increased, the pressure sensation becomes painful. Here also the sensation does not

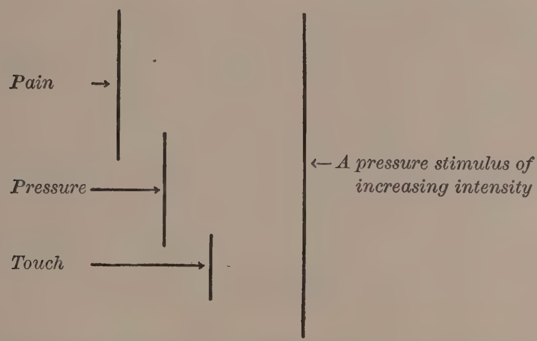


DIAGRAM XLII. The relation of the sensations of touch, pressure, and pain to the increasing intensities of a pressure stimulus.

change one of its characteristic qualities, but a new sensation, *i.e.*, pain, has been added to the pressure sensation. Psychical analysis considers the painful pressure sensation as a combination of two sensations, one of pain and one of pressure. If we wish to represent graphically the relation of touch, pressure, and pain to the physical stimulus, we should place the varying intensities of the pressure stimulus on the same continuous straight line, but we are compelled to use three different lines to represent the three discrete qualities of touch, pressure, and pain. These three lines have a length proportional to the number of variations in intensity of which the respective sensations are susceptible.

A sensation received from any intense stimulus may be disagreeable, even painful; thus the bitter of quinine is

disagreeable. Any extremely loud or penetrating sound is disagreeable. Odors are accompanied by similar elements of agreeable or disagreeable feeling. This fact has given rise to a theory that all sensations come into consciousness with a *feeling tone* as an integral part. The sensation is thus considered to possess three characteristics, its quality, its intensity, and its feeling tone. If the requirements of introspective analysis are adhered to, it is necessary whenever two qualities of sensation are distinguishable to treat these not as two characteristics of one sensation, but as two different sensations in intimate combination. It is therefore more appropriate to maintain that every sensation may have associated with it a "feeling" element, which may be either one of agreeableness or one of disagreeableness. The sensation of pain is as different and as distinct from all other sensations as is the sensation of color. It is also distinguished from agreeableness and disagreeableness.

To explain fully the nature of this association of "feeling tone" with sensation would lead us far into the field of physiological psychology. It will suffice, to call attention to the fact that when an external stimulus acts upon the body its total effect is not merely the sensation ordinarily excited by it. Every stimulus produces more or less remote effects upon many portions of the body. Thus ammonia may stimulate the sense organ of smell to give rise to a sensation of smell, but it also acts through the brain and spinal cord to affect the heart and breathing. Every such change in the body has a mental accompaniment which will be associated with the primary mental resultant of the stimulus. The reflex stimulation of remote portions of the body takes place so rapidly that these mental resultants are combined with that of the stimulus. A suffocating odor gives rise to a sensation of smell and also produces the changes in breathing that tend toward partial suffocation. The sensations due to suffocation are combined with the true sensation of odor. Although we may speak of a suffocating odor, the odor sensation

itself is not suffocating. One and the same odorous substance produces both an odor sensation and a suffocation sensation. Nauseating tastes are in like manner combinations of true taste sensations with sensations due to the reflex stimulation of other bodily processes. Thus the nausea element is connected with the stomach and the muscles of the oesophagus concerned in the reflex act of vomiting. The bitter sensation is almost invariably accompanied by a certain even though slight sensation of nausea. Other stimuli produce vigorous bodily reactions as well as sensations, for example stimuli of pain and stimuli of extreme heat and cold. Intense light stimuli act not only upon the retina but also upon the conjunctiva. They therefore produce sensations of light from the retina, intimately combined with sensations of pain from the conjunctiva. Some of the simpler emotions, for example fear, are characterized by mental elements due to the reflex effects of a stimulus. Would we "fear" a thunderstorm did not the intense light and sound stimuli cause the heart to beat violently and the breathing to become irregular, and also act upon the muscles to produce a temporary weakness and trembling of the limbs? The feeling tone of agreeableness and disagreeableness associated with sensations is in like manner due to combined elements which have an origin elsewhere in the body than in the sense organs and nerves directly excited by the stimulus. Some of the elements constituting a composite sensation have an internal physiological origin alone, while others have an external physical origin.

In Chapter I it was said that a sensation as a strictly simple mental content does not exist, because the mental result of every stimulus shows some degree of modification by apperception. In the immediately preceding chapters it has been shown that a sensation never exists alone but always in combination with other sensations of both external and internal origin. Those mental contents which the psychologist commonly

describes as sensations are therefore in reality sensation complexes, as, for example, a sensation of red, which is a complex of brightness and color sensations. It is the object of analysis to ascertain the particular constitution of each complex of sensation. In the endeavor to reach an element which shall be uncombined with other elements, psychology defines the sensation as a simple and immediate mental content, placing before itself an ideal of analysis rather than an actually existing mental content.

It is not possible to classify sensations as ideally simple mental contents. Sensation complexes, that is, sensations as we actually experience them, may be classified with reference to their relative simplicity and specific quality, or to their physiological or physical source. Different psychologists will make different classifications according to the basis taken. The older classification of sensations into five groups or "senses" is based upon the relation of the sensations to the physiological processes of gross anatomical structures, *i.e.*, the eye, ear, nose, mouth, and skin. It is a convenient although superficial classification; it has no important psychological or physiological significance. The following classification is based upon the qualitative specificity of the sensations. These classes are not "senses" in the ordinary meaning of that term: they are groups of sensations arranged in order from the least to the most qualitatively specialized sensations.

1. Organic sensations. These include particularly hunger and thirst and those vague sensations dependent upon a diffused internal stimulation anywhere within the body. It is probable that different portions of the body give rise to general organic sensations differing slightly from sensations of similar origin elsewhere. Thus the right arm may have a different "feel" from the left arm, owing to the regional quality of the organic sensations therein excited.

2. Kinaesthetic sensations. These differ qualitatively depending upon the region of the body from which they come.

Closely connected with these are sensations of rotation and dizziness and the other sensations arising from the maintenance of bodily equilibrium through the coördinated action of the muscles. Kinaesthetic sensations are important elements of visual and auditory sensations, and in fact it is impossible to prove that any sensation exists without some admixture of kinaesthetic sensation.

3. Sensations of tickle, tingling, motion over the skin, and the like.

4. Sensations of touch, pressure, heat, cold, pain, salt, sour, sweet, bitter, and sensations of smell. These are placed in one class as being of about the same order or degree of specificity.

5. Auditory sensations.

6. Retinal sensations. Combined with kinaesthetic sensations from the muscles of the eye, these are commonly known as visual sensations.

APPENDIX

The following list gives the number of every experiment requiring any kind of appliance, material, or apparatus other than the experimental charts, its page number, and the appliances called for. Experiments that can easily be omitted without breaking the continuity of the course are marked with an asterisk. In most cases, these are supplementary to experiments that are performed with simple apparatus.

Exp. 5, C, p. 16. A book. (Other common object.)
6, A, p. 19. A visiting card. (Piece of cardboard or heavy paper.)
6, B, p. 20. Three small boxes of different size and same shape. (Pill boxes or bottles.) Shot or sand. Cotton. (Any material to keep the shot or sand from moving about in the box.)
*6, C, p. 20. Two boxes (pill boxes, flasks, or bottles). Shot or sand. A balance.
7, B, p. 23. Paper and pencil for dictation.
8, p. 24. Two sheets of heavy paper or thin cardboard. Paper and pencil. Knife or scissors.
9, A, p. 25. A watch. A tape, yardstick, or foot rule.
9, B, p. 26. Five sheets of paper. Pencil or pen and ink. Measuring tape or rule.
10, A, p. 27. Same as in 9, A.
10, B, p. 27. Same as in 9, B.
11, B, p. 28. A watch.
12, A, p. 31. A mirror. A lighted match.
12, B, p. 31. A mirror. Two books. (Other common objects.)
*13, B, 2, p. 43. Two candles or lamps. A pencil. Several pieces of sheet glass of different colors.
14, A, 3, p. 48. Cardboard. (Visiting card.)
15, A and B, pp. 50 and 52. Blackboard and white crayon, or paper and pencil.
15, C, 1, p. 53. Same as in 15, A. In addition, letters cut from printed matter. A straw or pencil.
15, C, 2, p. 53. Same as in 15, C, 1. In addition, a tape or rule.
15, D, p. 54. Same as in 15, C, 2.
16, A, p. 54. Same as in 8.
16, B, 1, p. 59. Pencil (any hard object, as a key or hammer).
16, B, 2, p. 60. Paper and pencil for dictation.
19, A, 4, p. 90. Three small coins.

Exp. 19, D,	p. 94.	Paper and pencil.
21,	p. 109.	Cane or pencil (or any sticks approaching these in size).
22,	p. 110.	A lead pencil.
23, A,	p. 113.	Small piece of black cardboard (white will do). A pin or needle.
*23, B, 2,	p. 118.	A dark room. A candle.
24, B,	p. 119.	Same as in 23, A.
C,	p. 121.	Same as in 23, A. In addition, a tape or rule.
25,	p. 124.	Two coins.
27, B,	p. 132.	A pair of dividers (compasses) and a measuring rule.
27, C,	p. 132.	Small piece of cardboard or heavy paper. A lead pencil.
27, D, 1,	p. 136.	Same as in 27, C.
27, D, 2,	p. 136.	Paper, pencil, rule, and scissors.
27, D, 3,	p. 136.	A small piece of cardboard.
27, D, 4,	p. 136.	A sheet of paper of foolscap size. Pencil.
27, D, 5,	p. 136.	A mirror.
28, A,	p. 138.	Pencil or penholders of different color or shape.
28, B,	p. 138.	Cardboard.
28, C,	p. 139.	Cardboard, knife (or scissors), pencil.
28, D,	p. 140.	Sheet of note paper and red or black ink.
29, A and B,	p. 141.	Two coins and a piece of cardboard.
30, A,	p. 143.	A long, thin book.
30, B,	p. 144.	Same as in 30, A. In addition, a rod or pencil.
30, C,	p. 144.	Cardboard.
31, A,	p. 149.	Paper and pencil and a measuring rule.
*31, B,	p. 149.	Hering's binocular test apparatus.
*31, C,	p. 150.	A large sheet of cardboard, string, and several bullets or marbles. A knife. (A long narrow box.)
32, A,	p. 154.	Two small pieces of cardboard (visiting cards) and a pair of scissors.
32, B,	p. 154.	A pair of dividers or compasses, or cardboard and scissors.
32, C,	p. 154.	A straw or slender strip of wood. White paper and paste. Knife or scissors.
33, A,	p. 155.	A piece of ice. A bit of slightly heated metal. Receptacle for holding water.
*33, B,	p. 155.	The Cattell pressure algometer.
33, C,	p. 155.	A blackboard or sheet of medium gray paper. Standard red, yellow, green, blue, black, and white paper. Pencil or straw. Colored crayon, pencil, or ink.
34, A,	p. 158.	Pencil cooled and slightly heated. (Any metal point.)
34, B,	p. 158.	Same as in 34, A. In addition, a fine pointed pen, red and black ink, a hand magnifying glass (not absolutely necessary), and a measuring rule.
34, C,	p. 158.	Sharpened match stick.
D,	p. 160.	A pair of blunt dividers or compasses and a measuring rule. (An aesthesiometer.)
35,	p. 165.	Sugar, salt, quinine or quassia, vinegar or tartaric acid, and salt. Four receptacles for holding solutions. Four camel's-hair brushes or pipettes (medicine droppers). Water to rinse the mouth, and a pan to hold the rinsings.

Exp. 36, A, p. 166. Several tuning-forks of different pitch, or a piano, violin, guitar, or any musical instrument.
36, B, p. 166. A tuning-fork or any simple stringed instrument.
36, C, p. 167. Three tuning-forks. (Any stringed instrument.)
37, A, p. 172. A sheet of white paper and a glass prism. A beam of sunlight.
37, B, p. 174. The color top (or wheel), three white discs, blue and yellow water colors, and a camel's-hair brush.
37, C, p. 176. A small sheet of standard blue paper and a shade of blue. White and light gray papers.
37, D, E, and F, pp. 177, 178, and 180. The color top (or wheel) and discs of various colors.
37, G, 1, p. 181. Colored worsteds, silks, or papers.
37, G, 2, p. 181. The color top (or wheel) and discs of various colors.
38, p. 183. A two or three pound weight, a string, and a soft cushion.
40, B, p. 186. A feather.
40, C, p. 186. A pencil and a measuring rule.
41, A, 1, p. 187. Two vessels of hot and cold water.
41, A, 2, p. 187. Several boxes of different size. Shot or sand.
41, C, 1, p. 188. A small piece of wood, cloth, and metal.
41, 2, p. 188. Three vessels of water at different temperatures.
41, 3, p. 188. Two vessels of water at different temperatures.
41, D, p. 189. A vessel to hold water and a Bunsen burner or spirit lamp. (Any source of heat.)
41, E, p. 189. Large vessel of water.
41, F, 1, p. 189. Plate of glass (any hard, smooth surface), a hair, and a score of thin sheets of ordinary writing paper.
41, F, 2, p. 189. A rough and a smooth covered book or sandpaper of different grades.
42, 1, p. 190. A menthol pencil.
2, p. 190. A sharpened match stick and a slightly heated needle.
43, A, p. 195. Eight wooden sticks from a xylophone or made by cutting a strip of wood one inch wide and a quarter of an inch thick into pieces of different lengths. Resonators tuned for specified vibration rates and fitted to hold in the external ear, as those of Helmholtz or König (not essential).
43, B, p. 195. Any musical instrument (violin, guitar, zither, xylophone, or piano). A stringed instrument (the sonometer or monochord).
43, C, p. 196. Two tuning-forks of the same vibration frequency, and wax. If the tuning-forks are not attached to resonance chambers, wide-mouthed bottles partly filled with water may be used to reinforce the sound of the forks. The fork is held over the mouth of a bottle, and the amount of water necessary to give the strongest reinforcement is ascertained by trial.
43, D, p. 197. Any stringed musical instrument or six tuning-forks.
44, A, p. 200. Watch and measuring tape or rule.
*44, B, p. 201. Siren and Galton whistle. (Steel bars or tubes to test the upper limit of audibility of sounds.) Bellows to operate the siren.
*45, A, p. 202. Touch weights after Scripture.

Exp. 45, B, p. 202. Salt, sugar, quassia or quinine, and tartaric acid. Vessels to hold solutions of these substances. Pipettes (medicine droppers).

*45, C, p. 202. Pressure algometer after Cattell or Macdonald.

46, p. 203. Two tuning-forks of the same vibration frequency, and wax.

47, A, p. 204. Two wide bottles (or boxes). Shot and sand. A receptacle. A balance.

B, p. 205. The same as in 47, A.

47, C, p. 206. Four boxes (pill boxes) filled with shot and sand, to weigh 100, 101, 104, and 112 grams, respectively.

47, D, p. 206. Three boxes. Shot and sand. A receptacle. A balance.

47, E, p. 207. Several boxes partly filled with shot and sand in as 47, A–D, but to have different prescribed weights.

48, p. 219. Various tastable and odorous substances. (To be done at home.)

49, p. 220. A small bit of metal (some object of metal, as a key) heated and cooled.

50, p. 222. Pencil. Some heated object. Ice. (To be done at home.)

Most of the material and appliances called for by these experiments will be found readily at hand or may be purchased at very small expense in general stores. Other supplies and special instruments may be obtained through the following firms and laboratories. Some instructors may desire instruments of precision and apparatus or appliances of demonstration not called for by the Manual. It is recommended that catalogues and price-lists be secured.

Milton Bradley Co., Springfield, Mass. (The color top, color wheels, papers, and other general materials.)

Chicago Laboratory Supply and Scale Co., 31–45 W. Randolph St., Chicago, Ill. (General supplies and special instruments.)

E. B. Meyrowitz, 104 E. 23 St., New York City. (Optical and acoustic instruments.)

Michigan Apparatus Co., 305 So. Main St., Ann Arbor, Michigan. (Special instruments.)

Prang Educational Co., 7 Park St., Boston, Mass. (Color materials.)

Queen & Co., 1010 Chestnut St., Philadelphia, Pa. (General supplies, optical and acoustic apparatus, and special instruments.)

Williams, Brown & Earle, 918 Chestnut St., Philadelphia, Pa. (General supplies and apparatus, and special instruments.)

Columbia University Laboratory, New York City. (Cattell's instruments.)

Yale University Laboratory, New Haven, Conn. (Scripture's instruments.)

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